Research Note 81-16

AN ANALYTICAL MODEL FOR DEVELOPING OBJECTIVE MEASURES OF AIR CREW PROFICIENCY WITH MULTIVARIATE TIME SEQUENCED DATA

VOLUME I. ANALYSIS AND RESULTS

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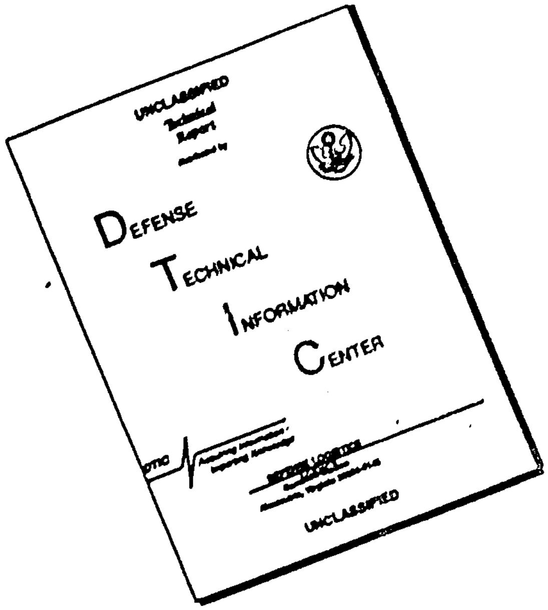

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This report represents a theoretical investigation of analytic methods for deriving differential weighting functions from preselected samples of multivariate, time sequenced observations of aircrew performance. The research effort resulted in an analytic model which could be used to prepare and to further investigate differential weighting functions as a means of establishing relationships between time sequenced observations of aircrew performance and independent assessments of aircrew proficiency. (over)

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A companion report, Volume II. Computer Program Documentation (RN 81-17), provides documentation of the basic computer programs used in the processor termed "Measurement Analysis Processor" (MAP).

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INTRODUCTION

The increasing costs of training and the inherent risks of flight in the Nap-of-the-Earth (NOE) regime require that the Army develop more efficient aircrew training programs. Previous research by PMA (Connelly, Comeau, Bynum & Holman, 1979) to improve NOE navigation evaluation methods has shown that subsequent improvements in the efficiency of NOE aircrew training programs will be dependent on a research need for better quality data in the evaluation of aircrew proficiency. The quality of existing data is constrained by the process of instructor pilot observation as its source. The instructor pilot has other duties, such as safety and backup pilot, which must take priority over any formal observer or data recording functions needed to support research analyses. Therefore, data yielded by instructor pilot observations does not readily allow for detailed investigations of such factors as aircrew workload or specific NOE mission requirements and their effects on instructor pilot ratings of overall quality of aircrew performance.

The US Army Aviation Center is studying the development and installation of a fully instrumented NOE training and test range. This range will have electronic technology to collect, via telemetry, comprehensive time sequenced data on aircraft location, aircraft attitude, and aircraft control states at all times during selected flight sorties within the range boundaries. The time sequenced observations provided by this instrumented range will yield an immediate solution to the research need for greater levels of detail in performance observation. However, a concomitant result will be a massive data base for each flight sortie.

Specialized methods of analysis must be developed to fully utilize the resulting level of detail because existing statistical models give equal weight to each data point in this massive data base. Equal weighting of each data point is known to be invalid because previous research by PMA (Connelly & Loental, 1974a) has shown that the probability of aircrew performance errors will depend on particular locations, events, or functional segments within the mission flight profile.

A detailed analysis of performance of various types of aircraft missions has shown that the significance of flight errors and flight control styles to mission success is not uniform over the total mission profile. For example, rapid reduction of a flight error such as an altitude error may be important to mission success at one point in the mission, but is of less importance, and perhaps even wasteful of crew members' energy, at other points in the mission.

Evidence of the varying importance of control is obtained from many sources. In an analysis of an F-106 attack mission, Connelly & Loental (1974a) showed that superior performers used different control policies for each of the three strategies of the mission (Prelock-on, Lock on, Postlock-on). Pilots who did not perform as well on the total mission did not use that varying control strategy. In another example, Connelly, Schuler, Bourne, & Knoop (1971), in developing performance measures for undergraduate students flying pilot contact maneuvers, found that specified relationships between pitch and roll were not rated equally by instructors at all points in the maneuver. Coordination appeared to be most important at the beginning and the end of the maneuver. In yet another illustration of this point, Connelly, et al, (1979) found that performance of NOE navigators was sensitive to combinations of terrain and flight path conditions along the specified route. In some terrain conditions the probability of success was found to be high while other terrain conditions led to more frequent navigation errors.

In the past, the measurement of mission performance was limited to summary measures which provided a single score for the total mission performance. As a result, these measures could not be used to evaluate the varying sensitivity of control during the mission. More recently, because sensitive measures have been required, the technology for these measures has been developed. In addition, the use of automatic electronic data collection systems permits collection of data on a near continuous basis, thus providing the information required for the sensitive measures.

Sensitive system performance measures are obtained by utilizing a function of a flight error and its rate of change. This function embodies the measurement principle "A sensitive measure of an event or condition is the distance to that event or condition." This means, for instance, that the condition "error is within tolerance" is replaced by the function of the distance and velocity to the tolerance condition. Performance measures developed from this concept are able to detect instantaneous changes in response patterns. And, with suitable weighting functions are able to determine the effect of that change in the response pattern on the total mission performance. These measures are termed "system performance measures" since they reflect the effect of moment-to-moment control responses on the total mission performance.

Technical Objective

The technical objectives of the program, in terms of the capabilities of the analysis model, are given in the following paragraphs.

The purpose of this research is the theoretical investigation of analytic methods for deriving differential weighting functions from preselected samples of multivariate, time sequenced observations of aircrew performance. The research effort resulted in an analytic model which could be used to prepare and to further investigate differential weighting functions as a means of establishing relationships between time sequenced observations of aircrew performance and independent assessments of aircrew proficiency.

Inputs to the analytic model are multivariate, time sequenced data representing objective observations of a flight sortie on a designated NOE mission profile. The model is an empirically-based processor where the input data should be preselected to represent aircrew performance across a range of known proficiency levels. In most cases these input data will have been generated by some automated process, however, this does not exclude the possibility of data obtained in specialized instructor pilot observations or of data selected to represent other specialized features of a given mission.

The model output is a set of weighting functions. These weighting functions are derived from analysis of aircrew performance errors and rates of change of error states as a function of designated locations, times, or other operational segments within the relevant mission profile. The model can provide an estimated distribution of aircrew proficiencies across the various functional segments which constitute the entire mission profile. Further, the model can transform established weighting functions into values which are compatible with the routine analyses of time sequenced data using existing statistical models such as linear regression or Fourier analysis.

The derived weighting functions permit the following determinations:

1. Differentiation of relative difficulties of aircrew performance across known operational segments, or time dependent events representing significant changes in the mission flight profile or mission requirements.

2. Differentiation of operational segments, or time dependent events which best discriminate among known levels of proficiency in given aircrew performances of a specified mission.

3. Establishment of design requirements for subsequent automation of particular measurement system realizations to support routine evaluations of aircrew training performances.

ANALYSIS MODEL

Method of Approach

Performance of manned systems is limited by our ability to measure system and component subsystem performance in a reliable and sensitive manner. Without adequate performance measures, there is no way to produce and test system designs, plan and execute training systems, or evaluate operational systems. Methods of developing these performance measures can be characterized by the way in which performance criteria are obtained.

One approach which can be used when all factors that limit performance are known and quantified is an analytical method. For example, if a problem requires that an aircraft climb to a specified altitude while conserving fuel during the climb, the criterion, i.e., minimization of fuel, could be precisely defined analytically. Frequently, however, problems cannot be solved analytically, but demonstrations of superior as well as less than superior performances are available. In these cases an empirical approach can be used. This report describes an empirical method for analyzing simulator flight data to develop weightings that permit performance discrimination between two groups of student pilots (one group of students successfully passed the initial Army rotary wing training program at Ft. Rucker, Alabama. The other group of students did not pass that training course.).

Background

Work on the System Performance Measure Concept was initiated in the latter 1960's and first reported in a paper entitled "A Theory of Adaptive Man-Machine Systems Applied to Automated Training" (Connelly, Schuler, 1969). That paper presented the general concept and theory of system performance measurement within the context of continuous performance measurement as applied to a training problem. At that time only solutions to simple control tasks could be obtained.

While development of techniques for continuous measures has continued, the major step in the realization of system performance measurement was the recognition that the measures might be derived empirically by the analysis of performarces demonstrating various levels of skill. The work on an empirical way of generating measures was supported by the U.S. Air Force Human Resources Laboratory (HRL/ASD). The first report of this work is Connelly, Schuler, & Knoop (1969).

The first application study for this empirically based methodology was the development of measures for contact maneuvers flown by undergraduate student pilots. The technique was at that time referred to as "adaptive math models" and was reported in Connelly, Schuler, Bourne, & Knoop (1971).

Another application required additional technique development (Connelly, Bourne, Loental, & Knoop, 1974), and produced a computer processor which worked semi-automatically with the user to generate performance measures from performance data. This processor was delivered to the Human Resources Laboratory (ASM) at Wright-Patterson Air Force Base and installed in the Sigma V computer at that facility. The processor can accept performance data consisting of time samples of important state variables (such as the variables describing the motion of an aircraft, and the control inputs) which describe each performance of a task. In addition, the processor accepts a summary evaluation of each task performance. The processor then assists the user in searching the data to find discriminate functions which can be used to predict the summary measure value. These discriminate functions are the desired system performance measurement functions.

The empirical technique has been used to develop performance measures for one-on-one air combat (Connelly & Kuhns, 1974), F-106 attack mission (Connelly & Loental, 1974a and 1974b), helicopter navigation (Connelly, Comeau, & Laveson, 1975, and Connelly, Comeau, Bynum, & Holman, 1979), and ship collision avoidance (Connelly & Sloan, 1977). Other applications have included modeling of decision-making tasks and development of measures for fire departments (Connelly & Swartz, 1977). The method was summarized for a NATO audience by Taylor and Knoop (1972).

Recently the method was applied to the development of performance measures of Army teams using computerized tactical data equipment. This effort is notable because the application does not require knowledge of the performance-limiting effect of the controlled equipment as was the case with previous applications. Instead, it is recognized that demonstrations of performance implicitly include the limitations of performance, and that the measures can still be derived using the same methodology. Another advance in this effort was the development of the measure for teams which are based on generic categorization of team tasks including team interactive tasks. This work is documented in Connelly, Comeau, & Steinheiser (1981).

MAP Processor Description

The MAP Processor is a computer processor that, under user control, searches performance data seeking functional relationships among system variables that permit performance prediction. The processor is used where demonstrations of task performance are available along with an independent assessment of the value of each performance. Performance data consists of the value of system variables typically sampled at uniform intervals of time from the start to the end of the task. System variables consist of all variables needed to describe the condition of the system (i.e., the condition of the process controlled by the operator) at each instant of time. System variables are often referred to as state variables by control engineers and mathematicians. Examples of tasks that can be analyzed with the MAP Processor are extensive and include: a pilot controlling an aircraft in a landing, a computer operator controlling a computer, a computer programmer writing computer code, and a project manager controlling a project.

The independent performance assessment can be either a subjective or an objective assessment. It could, for instance, consist of a subjective rating reflecting a preference for each performance demonstration - such as scoring of a boxing match, ice skating, and diving performance in competitive sports. In other cases the assessment can be objective, such as distance off target, number of data entry errors, time to complete a task, and cost to complete a task. It is used to order (or cluster) performance demonstrations according to performance. The MAP Processor then forms and tests (by making Performance Predictions) functions of the system variables that order (or cluster) the performance consistent with that of the independent assessment. Functions formed and tested by the Processor and found to predict performance represent the relationships among system variables and performance. The functions can show how superior performance (and other performance categories) was achieved.

The MAP Processor is designed in two parts. One part, a transformer, converts the various forms of real world variables into a standard form for the search; the other part provides the search mechanism.

A block diagram of this system is shown in Figure 1 where the first part or interface portion of the process is denoted as "Boolean Questions." This system uses Boolean questions (questions which have a yes or no answer) to transform the real world variables into a set of Boolean variables which in turn, provide a standard form of input to the second part of the processor.

Boolean questions fall into two categories. One category is a set of questions used to identify the state of the process under study. For instance, if we are working with an aircraft landing problem, we are interested in the present condition of the aircraft. Thus, the state variables for that problem might include glide path error, aircraft velocity, pitch and roll angles, throttle position, and control stick position(i.e., all the variables required to uniquely define the present condition of the aircraft). Boolean questions associated with those variables might ask: Is the glide slope error greater than X degrees? Is the velocity error greater than 2 knots? Four knots? Six knots? Is the pitch angle of the aircraft greater than 1 degree? Two degrees? Four degrees? And is the heading of the aircraft aligned with the runway heading plus or minus 1 degree? Two degrees? Three degrees? When dealing with aircraft maneuvers, one might use Boolean questions to identify not only the type of maneuver, but also to identify the present segment of the maneuver. As suggested above, numerous questions can be asked to identify the state of the process under study.

It should be noted that using Boolean questions formulated to identify the state of the aircraft indeed reduces the amount of information retained about the process (i.e., instead of using state variables, the information is now encoded in Boolean variables). The idea is to retain only that information believed to be important to performance; however, if an error is to be made, it is best to accept more information than is necessary rather than less.

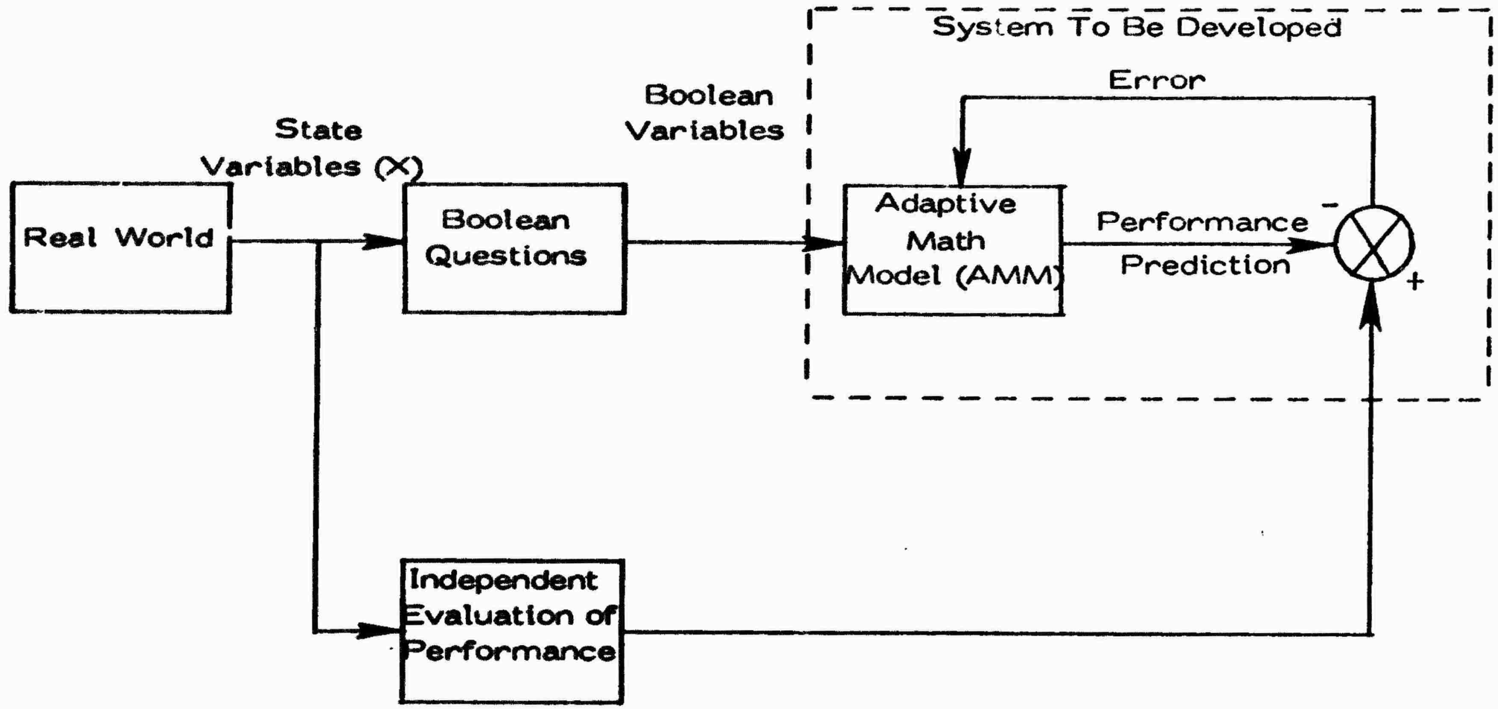


Figure 1. MAP Processor

Considering now the second Boolean category referred to above, questions are also used to represent the known or even suspected performance relationships. For instance, if we believe that the frequency of control stick reversals is an important indicator of performance, we can introduce a Boolean question which asks if the stick crossed over the center position during the last increment of time. If we believe that performance is a function of the size of deviation from the reference path, we can ask multiple Boolean questions which indicate the degree of deviation at a particular time. Further, if we believe that one variable is a function of another variable or set of other variables when superior performance is achieved, then we can include that candidate function as a Boolean question (e.g., Is aircraft velocity a function of distance to touchdown plus or minus specified error? In this case the Boolean question would read:

$$\text{Is } V < KD + E \text{ ? or } V > KD - E \text{ ?}$$

where V is the velocity, D is the distance to touchdown, and E is the specified error, K is a constant.

Typically, these candidate functional relationships are obtained from subject-matter experts by asking them what they think is important to performance. Other sources include handbooks and textbooks on the subject. Often, however, the functions can be developed empirically by analysis of data of performances rated excellent. Thus, if all performances rated excellent (or superior) are grouped together and a reference function is determined such that the function value at any particular instant is the mean of all of the demonstrations rated excellent (and another function computed as the standard deviation ($\hat{s}$) of the performance rated excellent), then Boolean questions can be formed to ask: Do the system variables satisfy that reference function $\pm 1\hat{s}$? $\pm 2\hat{s}$? etc. These Boolean questions can be applied to performance data from any group to determine the similarity of that group to those rated excellent.

Once the set of Boolean questions has been defined, they can be applied to the real world input data. Since the real world input data is time varying, the answers to the Boolean questions will also be time varying. As a result, the output of the first portion of the processor will be a set of Boolean time sequences (BTS) such as those shown in Figure 2. At any particular time, each Boolean variable, which is the answer to its corresponding Boolean question, will either have a yes or no value which can be expressed as 1 and 0 respectively in a digital computer. In this way, the first stage of the process converts the real world variables, which can appear in various forms, into a set of Boolean (or binary) variables, in a standard form.

Now consider the search portion of the processor, which incorporates three separate computational search mechanisms. Each of the sub-processors searches for and evaluates the utility of a separate type of performance-data characteristic.

The first of these three computational techniques is called the State Transfer Technique. This technique is designed to examine the relevance (to performance evaluation) of overall trends in the performance as evidenced by transfers from one system-state to another. A state of the system refers to the status of the total system as represented by the performance data taken collectively, i.e., it is the values of each Boolean variable at a given instant of time. The assumption of the State Transfer Technique is that performance evaluation is partially or totally a function of the dynamic change in system-states, i.e., it is based not on the present state of the system, but rather on the operator and system responses that occur, given the present state. The computational task is to determine a suitable state-representation of the data, and compute the significance of state transitions.

The second computation technique is called the Relative Technique. This technique is designed to examine the significance to performance evaluation of relationships among different performance variables as represented by the Boolean time sequences (BTS's). The assumption of the Relative Technique is that performance evaluation is partially or totally a function of specific (but presently unknown) relationships between or

	Sampling Interval						
	1	2	3	4	5	6	7 ...
BTS_1	1	0	0	0	0	0	1
BTS_2	0	1	0	0	0	0	1
BTS_3	0	0	1	0	1	1	1
BTS_4	0	0	1	0	0	0	1
⋮			⋮				
BTS_N	0	1	0	0	1	0	0

Note: A "1" represents a yes answer to the associated Boolean question.
A "0" represents a no answer to the associated Boolean question.

Figure 2. Boolean Time Sequences

among certain performance variables. (A very simple example of such a relationship would be that which exists between an aircraft's altitude and the distance of the aircraft from the runway threshold during an ILS approach.) The computational task is to detect such relationships, if they exist, and to discover how, if at all, they are relevant to performance evaluation.

The third computational technique is called the Absolute Technique. This technique is designed to examine the significance to performance evaluation of relationships between temporal patterns of each system variable and that of some (presently unknown) reference variable. The assumption, of the Absolute Technique, is that performance evaluation is partially or totally a function of certain relationships between actual performance and a fixed reference performance. The computational task is to find a suitable reference performance variable, to establish a method of comparing it with the actual performance variable, and to determine the significance of the resulting comparison.

The outputs of each of the three major computational models provide a component of the performance evaluation - a partial score. An additional analysis, a Regression Analysis, is used to combine the outputs from the three computational models to form a single score-prediction.

The next section of the report describes in more detail the state transfer computation using a phase plane analysis to provide the Boolean questions. Computer programs required to implement this computation and the other two computational techniques are also provided.

METHOD

As stated previously, only one of the MAP subprocessors was used in this effort - that of the state transition computation. The Boolean questions were generated automatically from a phase plane analysis as will be described.

The analysis methodology used recognizes that often during flight maneuvers some variables are to be maintained at a constant rate of change and that other variables are to be maintained at a constant level. For instance, in "straight and level" flight it is desired to have altitude, airspeed, and heading maintained at a constant level. Also, during a climb it is desired to have airspeed, and heading maintained at a constant level, and the rate of climb adjusted from 0 to some specified value and maintained at that value until the desired altitude is reached and then the rate of climb is to be reduced to zero to maintain the desired altitude.

One way to analyze the flight data to study pilot proficiency is to observe how closely these variables are actually maintained at a constant level, and also to observe the technique used to reduce errors once they occur. Flight errors may occur for several reasons including rough air and previous pilot error; but, it is as important to characterize error recovery procedures as it is to characterize maintenance of low errors when evaluating pilot capability.

An analysis tool that is often useful in evaluating pilot performance is a phase plane analysis which uses a plot of the error versus error rate of the variables of interest. For instance, when we are observing a pilot's control of altitude, we plot the altitude error (which might, for instance, be the deviation from a reference of 2,000 feet) against altitude error rate. If the pilot is to reduce the altitude error to zero and to maintain it at zero, he must, as will be shown, reduce both altitude error and altitude error rate to zero simultaneously. Thus, the phase plane shows how that objective is accomplished.

Calculation of error rate from flight data samples recorded at equal intervals of time is illustrated in Figure 3. Error rate is defined as the change in error divided by the change in time over a specified time interval.

An example of a phase plane plot is shown in Figure 4. Trajectory A, in that figure, is an oscillatory trajectory starting in quadrant 1 where both error and error rate are positive. If the positive error rate is not reduced, the error would just simply tend to increase without bound. But if the error rate is reduced to a negative value, the error itself is decreased as

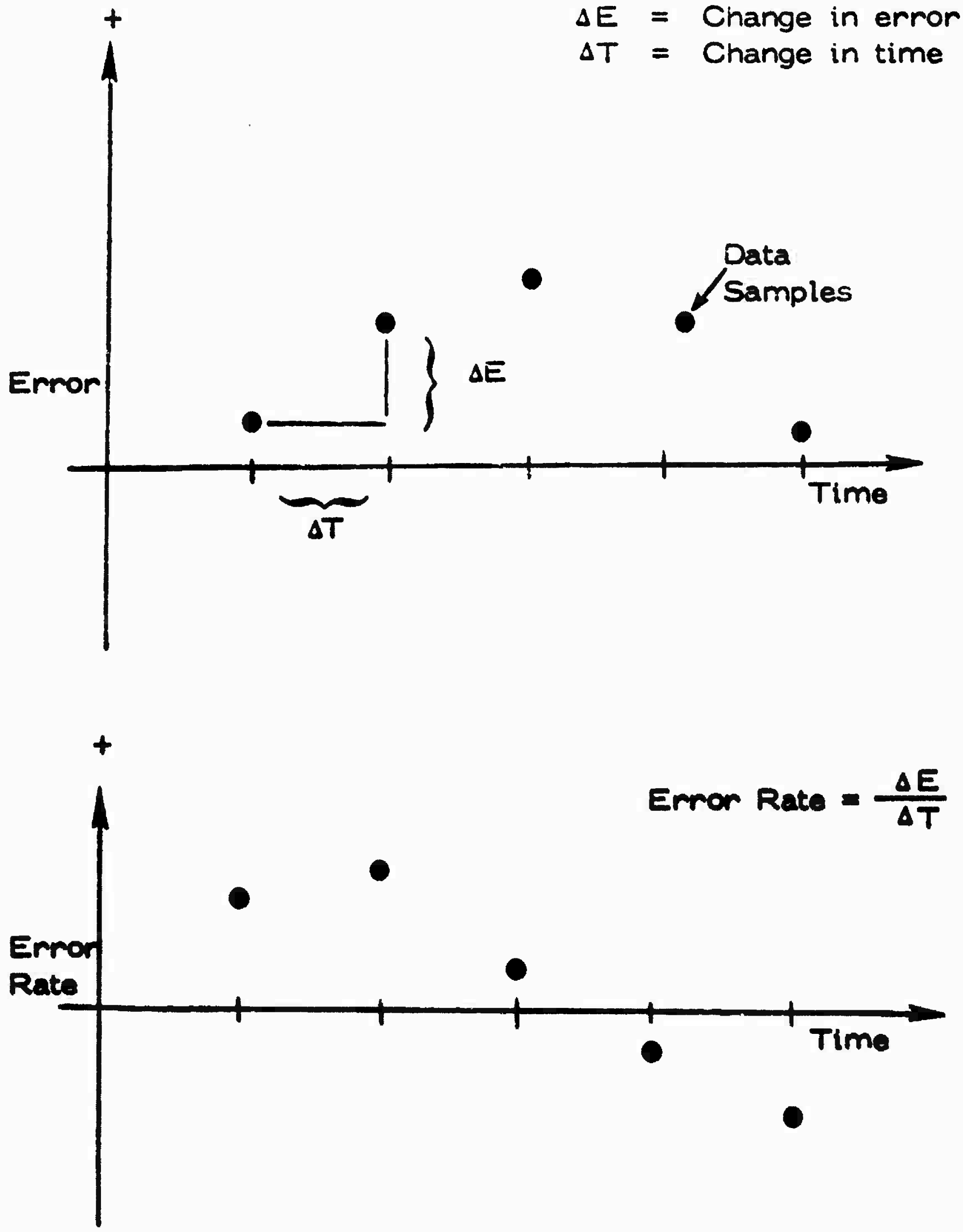


Figure 3. Calculation of Error Rate

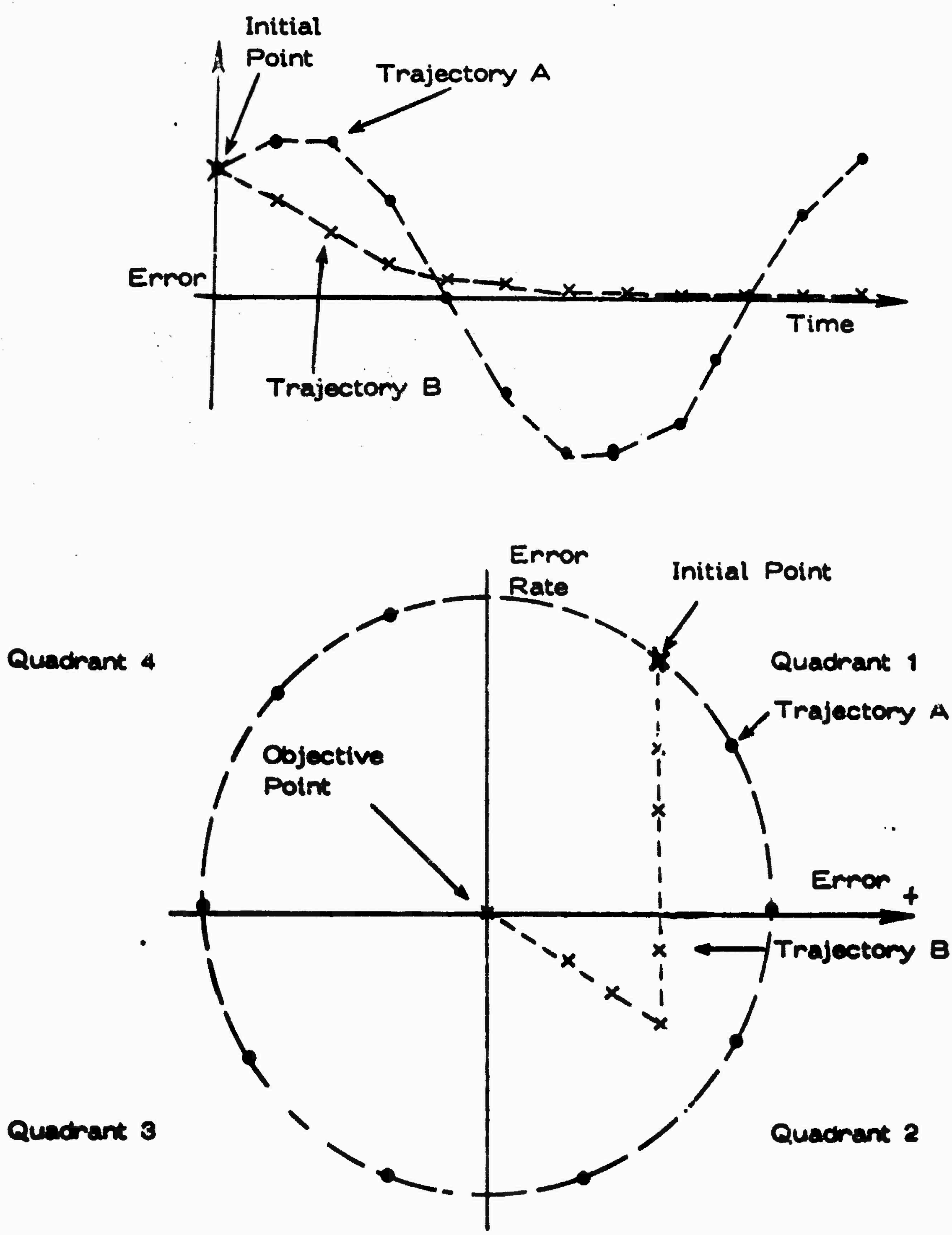


Figure 4. Trajectories in Phase Plane

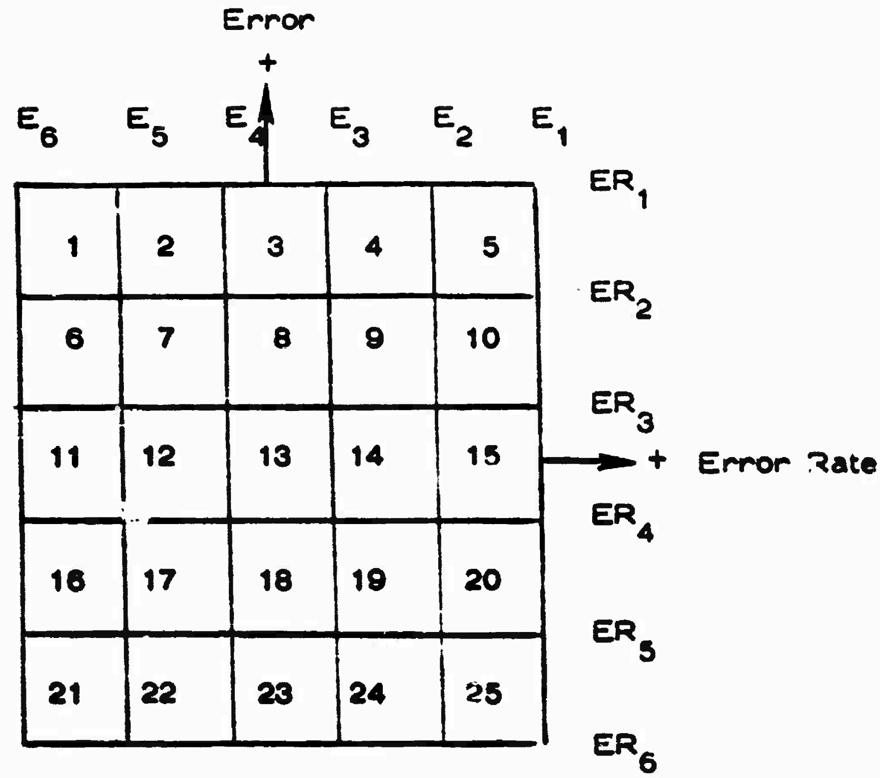
the trajectory moves into quadrant 2 (where error is positive and error rate is negative). If the negative error rate is not brought to 0 in that quadrant, the system then "overshoots" and moves into quadrant 3 where both the error and error rate are negative. Here again the error rate must be reduced to avoid more negative errors. Given the pilot controls the aircraft, to make the error rate positive again, he is faced with the problem of trying to reduce that error rate to 0 as the system moves into quadrant 4 where the error is negative and the error rate is positive. This process can continue with the aircraft oscillating about the reference altitude which corresponds on the phase plane to a circular or eliptical pattern.

The second example trajectory shown in Figure 4 starts at the same point as did Trajectory A and is identified by Trajectory B. The system starts with a positive error rate which is reduced to a negative value moving the system to quadrant 2; but then the negative error rate is brought to 0. This is the trajectory of a convergence system where the initial positive error is smoothly decreased to 0 without overshots.

Of course actual trajectories may not fit exactly into these two simple categories; but, these illustrations show the relationship between the more familiar time line trajectories and the corresponding phase plane trajectories.

Computerized analysis of the phase plane can be facilitated by converting the phase plane states into cells such as shown in Figure 5. Here the error and error rate variables are each divided into five categories which together make up 25 cells in the phase plane. The condition of the aircraft at any time with respect to any selected variable always falls in exactly one cell. That is, if we are observing altitude, the altitude error and error rate can be determined and consequently the corresponding cell in the phase plane determined. The analysis proceeds by observing the pattern of cell transitions. Thus, if the aircraft is in Cell 9, the convergent trajectory (B) might result in the cell sequence 9, 14, 19, 18, 13. On the other hand, oscillatory and divergent trajectories produce other cell sequences.

The cells in the phase plane can be considered as answers to two sets of Boolean questions. One set of questions determines the column corresponding to the error. And the



Note: Cell boundaries are set by error and error rate scale values specified by the user. The boundaries are:

$E_1 = \infty$	$ER_1 = \infty$
E_2 = +1.5 error scale	ER_2 = +1.5 error rate scale
E_3 = .5 error scale	ER_3 = +.5 error rate scale
E_4 = -.5 error scale	ER_4 = -.5 error rate scale
E_5 = -1.5 error scale	ER_5 = -1.5 error rate scale
$E_6 = -\infty$	$ER_6 = -\infty$

∞ = Infinity

Figure 5. Cells of the Phase Plane

other set of questions determines the row corresponding to the error rate. The answers to these sets of Boolean questions then identify the cell representing the present condition of the aircraft.

Cell boundaries, as determined by the Boolean questions, must be established so that the majority of flight data falls within the internal cells. A method has been devised to automatically establish all boundaries by scanning the data to determine the mean and variance of both the error and error rate. The cell sizes then are selected as a function of the error and error rate variances so that the cell sizes can be adjusted automatically to accommodate the majority of the flight data.

Transition Analysis Method

As an illustration of the analysis method, as shown in Figure 5, a set of Boolean functions divides the error and the error rate (phase) plane into 25 regions or cells. These Boolean functions automatically determine the present location (cell) of the demonstration data, which facilitates the state transition computation.

Several matrices are used in the transition analysis of operator performance. One is a 25 X 25 cell transition matrix whose elements are the probabilities of transfer from cell i to cell j from sample to sample. This matrix is constructed by counting the number of times the system is in each cell and makes each transition. If the resulting transition matrix (T) represents a regular Markov process (Kemeny & Snell, 1960) the state of the system after N transitions, starting from an initial state (cell) distribution represented by π_0, is given by

$$\pi_N = \pi_0 T^N \tag{1}$$

where T is the state transition matrix.

As N approaches infinity, there is a limiting distribution given by

$$\lim_{N \to \infty} \pi_N = \alpha \tag{2}$$

where α is the ensemble state distribution vector existing after a large number of trials. The limiting distribution can be regarded as the steady state distribution, such that

$$\alpha T = \alpha \tag{3}$$

A second matrix useful in analysis of operator control policies with transition matrices is defined by equation 4. This matrix is the weighted transition matrix, such that each element is given by:

$$D_{ij} = T_{ij}\alpha_i \tag{4}$$

The matrix, referred to as the D matrix, is obtained by multiplying each row of the transition matrix by the probability the ensemble will be in the corresponding state. The elements of the D matrix correspond to the probabilities that a particular transition (transtate) is used in a given control effort, and are used to generate a performance measure according to:

$$PM = \sum_i \sum_i D_{ij} \quad TSM_{ij} \tag{5}$$

where TSM is a transtate score (weighting) matrix whose element values transform the frequency of each transition into incremental scores which are summed according to equation 5 to provide the total score (PM).

The values of TSM are determined by a method described in Connelly & Loental (1974a).

General Analysis Procedure

We now consider the sequence of analyses performed on the data where each separate analysis is accomplished by a computer program. The listings for these programs are given in Volume II of this report.

Flight data for a number of student pilots was received from the ARI field unit at Fort Rucker on an IBM compatible 9-track magnetic tape. The tape was mounted on a tape deck at a time-share organization. Specified files from the tape were read into disc memory at the time-share facility. The data was then transmitted over telephone lines to floppy disc storage at PMA. In order to efficiently transmit the data, it was converted from integer to hexadecimal format at the timeshare facility. After transmission, the data was converted back to integer format from hexadecimal. Next, data for each selected student had to be stripped from composit files into separate student files. The various parts of a file had to be merged in order to reassemble it for a subject. With this data organization, the data analysis could proceed.

Figure 6 describes this analysis procedure in diagram form. The program INTHEX which was resident at the timeshare facility provided the integer-hex conversion and program HEXINT resident on PMA's LSI-11 converted the data back to integer form. The merging of files was conducted with a program called FMERGE. This program accepts data from parts of many files and constructs a new file in accordance with a student number. With this program, data concerning a student which were located on several different files on several different floppy discs could be reconstructed into a single student file. At this point in the analysis, data for each selected student were available on floppy discs.

The next step was to plot selected variables as a function of time on a "strip line" type plot. The program "STRPLT" which provides this plot accepts control inputs to identify the desired variables to be plotted. Variables plotted were: altitude, heading, airspeed, roll angle, and pitch angle as a function of time.

In addition, there are several other utility programs available such as "DFLIST" that lists all data on the terminal display, and "SEGID" which was intended to locate particular flight conditions. However, it was found that the STRPLT data were sufficient and it was not necessary to use SEGID.

Plot data were analyzed to first identify the beginning and end of each different type of maneuver, and then to identify segments in each type of maneuver where variables were supposed to be maintained by the student pilot at a constant level. Due to the volume of the strip plots, they were not included in this report but were delivered to the ARI field unit at Fort Rucker under separate cover.

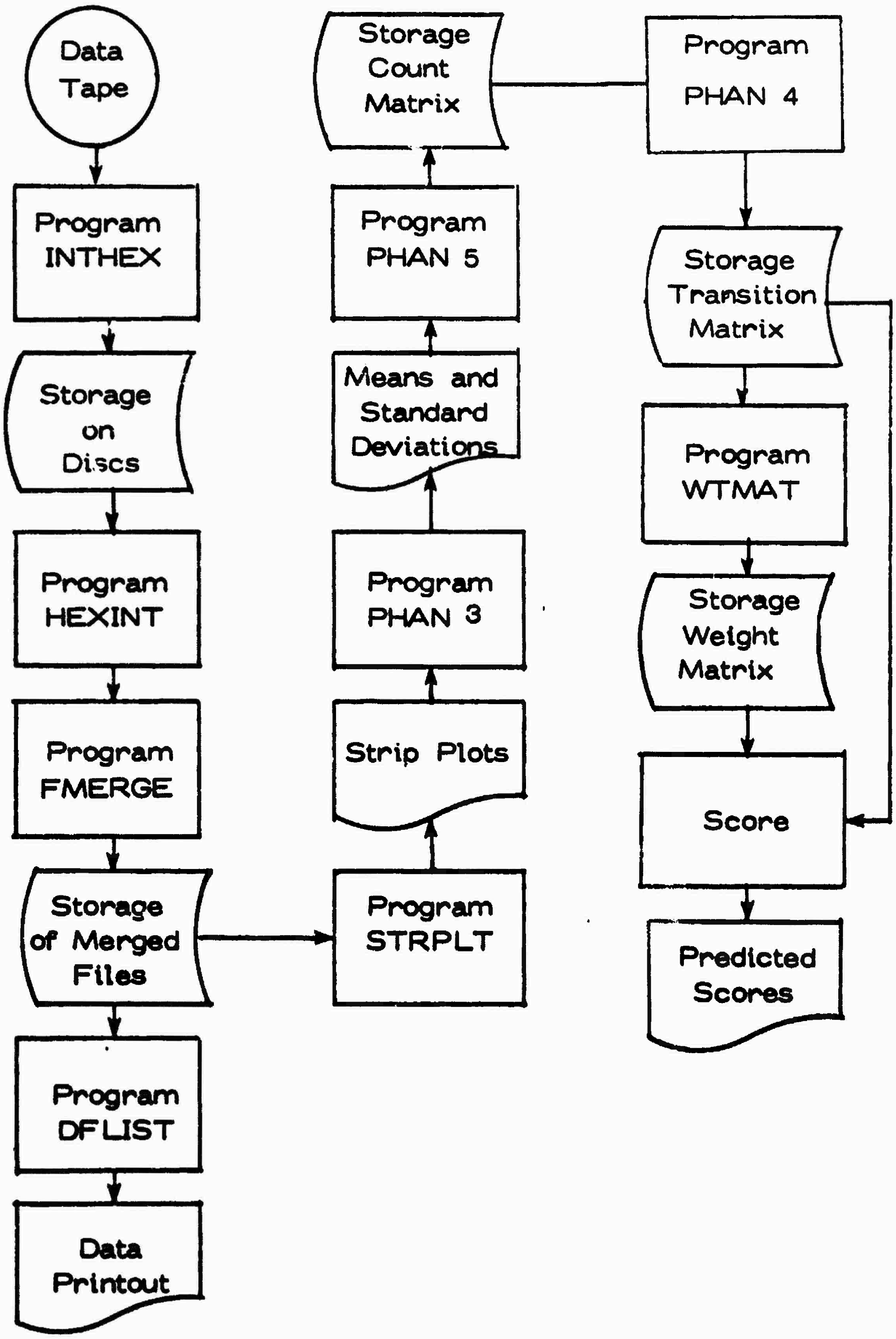


Figure 6. Overview of Analysis Procedure

The next step, performed with PHAN 3, was to compute the mean and variance of error and error rates of selected variables for students performing in specific maneuvers. The variables selected were: altitude, heading, airspeed, and rate of climb. These data were used to set the cell dimensions in the subsequent phase plane analysis.

In order to create a count matrix, Program PHAN 5 was used. The approach was to specify error and error rate scale values input by the user, so that the phase plane cell sizes, which were set as a function of the scale values, were fixed. Also, the mean error for each flight segment was input into the computer and subtracted from the segment data values. These segment mean values were taken from tables presented in Appendix B and entered into a computer file to be read by Program PHAN 5. PHAN 5, of course, also read the flight data file containing the time line data of the selected flight variables, and counted the number of times each cell was used, i.e., the number of times transition $i \rightarrow j$ was used. The output was a computer file containing the count data.

Under user control, Program PHAN 4 read one or more count matrices and produced a transition matrix. For instance, a transition matrix could be developed to represent performance of a single student or alternatively to represent all students in a particular performance classification.

As preparation for program WTMAT, the transition matrices for the two performance groups are appended along with two target group scores into a master data file. The organization of the appendix data file is shown in Figure 7. Since data for only two groups were used in this case the appended file contains two transition matrices followed by the associated target scores. Target scores are used by the WTMAT program as the true score for the associated group and it adjusts weighting values to attempt to predict the target score.

Next, Program WTMAT read the appended transition matrix file, determined the weighting required for discriminating among the performance categories specified, and output a weight matrix.

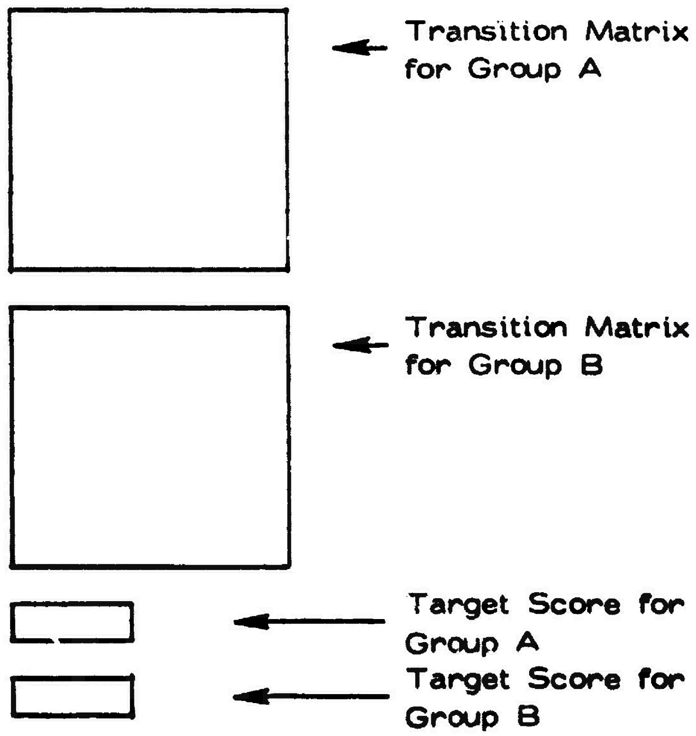


Figure 7. Appended Data File

Finally, program SCORE read the weight matrix along with a single transition matrix and calculated a score according to equation 5. If, for instance, a score is required for a number of students, the program could be run for each student using the transition matrix representing his/her performance.

Analysis 1

Purpose

To determine sectors in flight maneuvers corresponding to each different type of flight and compute mean and standard deviations for error and error rate for each selected variable.

Method

Strip plots of available data were output from the computer. The output, as shown in Figure 8, consisted of the values of altitude, airspeed, roll angle, heading, and pitch angle plotted at two second intervals. Scales for the Y axis are output prior to the plot and are not shown in the figure. Three columns on the left of the figure are from left to right respectively, a start/stop of maneuver sector (such as "begin climb" or "climb has ended"), a maneuver type index (8 shown in the figure), and a simulator clock. To the right of the figure are two columns which are the simulator clock repeated, and a line index number.

The line index number is used to identify the start/stop indices of maneuver segments.

Results

Tables B1 through B24, given in Appendix B, show for 6 students and 4 flight variables, airspeed, heading, rate of climb, altitude, the start and stop indices, and mean and standard deviations for the error and error rate. Only straight and level flight was considered in this analysis. The start and stop indices and means were entered into six computer files coded with "S" in the fifth digit of the file name (see Computational Plans in Appendix A).

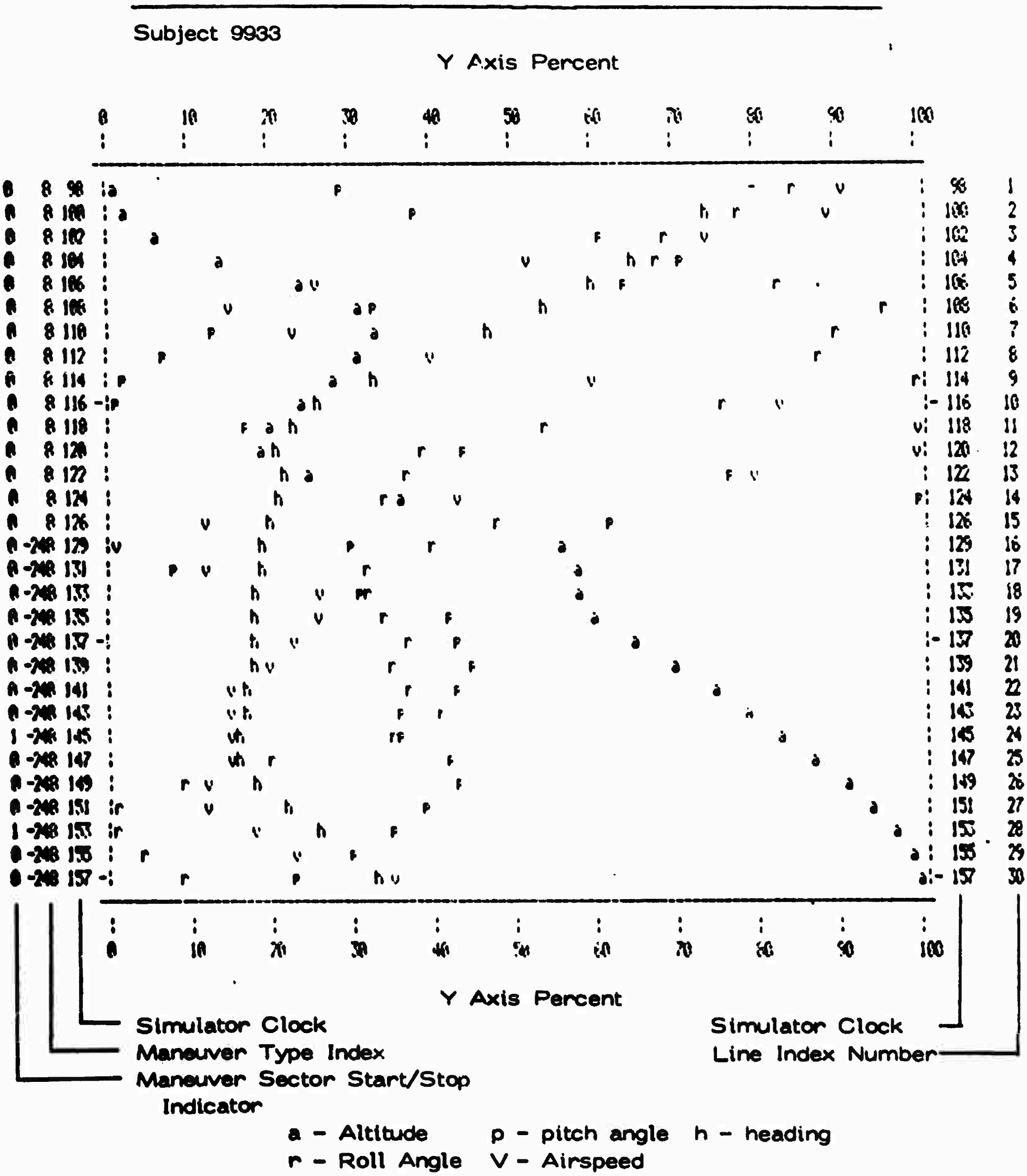


Figure 8. Example of Plot Format

Analysis 2

Purpose

To establish a method for computing weighting matrices that permit discrimination between the two categories of students.

Method

Analyses were conducted on performance data of six students of which three subsequently had passed (P) the initial entry rotary wing training course and the other three had not passed (F) that course. The numbers of the six students are:

1.	4935	(P)
2.	20935	(P)
3.	9935	(P)
4.	20933	(F)
5.	8933	(F)
6.	15933	(F)

The code used to identify each file in the computer and also used for shorthand notations in this report is defined in Appendix A. As an example, the code, "A491S1," is read:

A	Altitude Data
49	Student Number 4935
1	Straight and Level Flight
S	File contains Section Start & Stop Indices (Along with Mean Values for Error and Error Rates for the Section)
1	The First File Using the Five Digits Specified

The data analysis is organized into six computational plans, one for each combination of three aircraft variables (altitude, airspeed, and heading) and two student groups (Pass, Fail). These plans are given in Appendix A, Figures A2 through A8. Each computational plan gives the flow of data from the raw flight data to the score. On the left side of the diagrams, in caps, are the names of programs used to obtain the results (i.e., PHAN 3, PHAN 4, etc.).

While the data for each student is for straight and level flight and thus results are comparable with regards to establishing the computational method, the reader is cautioned that the straight and level flight segments are taken from different flight maneuvers for different subjects. Data for the subjects who passed were from early training sessions but for subjects who failed, data was taken from later training sessions. Later sessions permitted additional training but also involved more complex maneuvers of which straight and level was a part.

Results

Table 1 documents the error and error rate scale (standard deviation) values used to establish the phase plane cell boundaries. These values are called for by the PHAN5 program.

Tables 2, 3, and 4 provide the scores obtained when performance data of all six students were used to determine the score weight matrix for each of the three flight variables. Performance Measure A refers to the measure derived using all six students' performance data. The scores show that discrimination was possible within the data used to produce the score weighting values (analysis associated with Performance Measure B values is described in Analysis 3).

Although the number of students in each classification was inadequate to draw conclusions for the general population of students, it was possible to separate performance of the students based on analysis of only straight and level flight data.

Table 1

Scale Values for

Altitude, Airspeed, Heading

Flight Variable	Error Scale	Error Rate Scale
Altitude	80 feet	8 feet/sec.
Airspeed	3 knots	2 knots/sec.
Heading	6 degrees	3 degrees/sec.

Table 2

Student Scores

Altitude Control Performance in Straight and Level Flight

Student No.	Pass/Fail	Score A*	Score B**
4935	P	66.4	55.4
20935	P	72.4	69.0
9935	P	55.3	49.3
20933	F	33.05	36.7
8933	F	25.17	38.3
15933	F	45.87	41.4

* Score A was obtained using Performance Measure A which used the performance data from all six students to derive measure weights.

** Score B was obtained using Performance Measure B which used the performance data from students 4935, 20935, 8933, and 15933, i.e., students from each P/F category, to derive measure weights.

Table 3

Student Scores

Airspeed Control Performance in Straight and Level Flight

Student No.	Pass/Fail	Score A*	Score B**
4935	P	52.0	57.5
20935	P	74.8	73.5
9935	P	63.6	59.6
20933	F	22.8	30.8
8933	F	24.3	25.2
15933	F	32.1	32.4

*Score A was obtained using Performance Measure A which used the performance data from all six students to derive measure weights.

**Score B was obtained using Performance Measure B which used the performance data from students 4935, 20935, 8933, and 15933, i.e., students from each P/F category, to derive measure weights.

Table 4

Student Scores

Heading Control Performance in Straight and Level Flight

Student No.	Pass/Fail	Score A*	Score B**
4935	P	57.7	60.5
20935	P	53.9	58.9
9935	P	53.3	46.7
20933	F	39.0	52.6
8933	F	37.0	32.6
15933	F	29.0	31.8

*Score A was obtained using Performance Measure A which used the performance data from all six students to derive measure weights.

**Score B was obtained using Performance Measure B which used the performance data from students 4935, 20935, 8933, and 15933, i.e., students from each P/F category, to derive measure weights.

Table 5 illustrates the cell frequency usage for altitude control of one group of students. There are six such tables (2 groups x 3 control variables) which are given in Appendix C. These data are the 25 most frequently used cell transitions and are the corresponding elements of the "D" matrix. Recall from the theoretical presentation that the "D" matrix contains the probability that each transition occurs given that no additional information about the process was available, i.e., that the existence of a previous cell was not known.

It is interesting to note that the frequency of use of the transition 13→13 which reflects the frequency of a small error and small error rate was not a good discriminant of the two student categories since students from both groups had a high frequency of cell transition 13→13. However, the students who passed the training course tended not to leave Cell 13 once it was entered.

The probability transition 13→13 is closely related to "time in tolerance" which is frequently used as a performance measure in control systems. As suggested by the results cited above, time in tolerance is apparently not a good performance discrimination factor.

Tables 6, 7, and 8 contain the weight matrices derived for scoring altitude, airspeed, and heading performance respectively. Since all matrix entries were set initially at a value of 50.0, it was likely that those entries which were still at 50.0 were not adjusted to provide score discrimination among the two student groups. The maximum and minimum values allowed were 99.0 and 0.0 respectively. Scores with these extreme values were apparently associated with cell transitions predominatly used by one or the other classification of students. Intermediate score values (i.e., between 99.0 and 50.0, and 50.0 and 0.0) correspond to cell transitions used infrequently or by both student categories. Better insight as to the importance of these incremental score values can be obtained in the subsequent analyses.

Table 5

Probability of Cell Usage - Altitude

Students 20935, 9935, 4935

Student 20935			Student 9935			Student 4935		
Cells		Probability of Usage	Cells		Probability of Usage	Cells		Probability of Usage
13	13	0.0700	5	5	0.0819	13	13	0.0859
1	1	0.0687	12	12	0.0688	12	12	0.0661
2	2	0.0487	8	8	0.0677	16	16	0.0542
5	5	0.0479	11	11	0.0655	8	8	0.0399
25	25	0.0448	13	13	0.0528	5	5	0.0391
24	24	0.0336	15	15	0.0521	25	25	0.0385
12	12	0.0330	18	18	0.0472	11	6	0.0324
11	11	0.0324	6	6	0.0457	7	7	0.0299
6	6	0.0307	7	7	0.0323	6	1	0.0283
21	21	0.0306	25	25	0.0316	19	19	0.0276
7	7	0.0298	12	7	0.0256	9	9	0.0271
10	10	0.0293	21	21	0.0192	1	1	0.0267
18	18	0.0285	20	20	0.0190	10	10	0.0227
8	8	0.0280	8	13	0.0155	8	13	0.0209
19	19	0.0261	7	12	0.0148	14	19	0.0190
23	23	0.0251	7	8	0.0148	19	14	0.0181
14	19	0.0214	17	12	0.0137	9	14	0.0163
16	11	0.0207	18	17	0.0131	4	9	0.0158
21	16	0.0204	18	13	0.0131	20	25	0.0148
19	14	0.0196	16	11	0.0121	2	7	0.0143
24	23	0.0165	10	5	0.0118	1	6	0.0133
12	7	0.0163	19	19	0.0118	1	2	0.0133
11	6	0.0162	19	18	0.0118	25	20	0.0126
6	1	0.0139	11	6	0.0116	15	15	0.0120
19	24	0.0131	1	1	0.0116	15	5	0.0120

Table 6

Weight Matrix Straight and Level Flight: Altitude Control

Source Cell	Receiving Cell 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	95.	99.	50.	50.	50.	97.	99.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.
2	50.	99.	99.	50.	50.	50.	98.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
3	50.	50.	21.	50.	50.	50.	50.	97.	50.	50.	50.	50.	0.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
4	50.	50.	50.	99.	99.	50.	50.	50.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
5	50.	50.	50.	50.	93.	50.	50.	50.	50.	97.	50.	50.	50.	50.	47.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
6	98.	50.	50.	50.	50.	98.	0.	50.	50.	50.	0.	50.	50.	50.	50.	14.	50.	50.	50.	50.	50.	50.	50.	50.	50.
7	50.	98.	50.	50.	50.	50.	89.	98.	50.	50.	50.	95.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
8	50.	50.	0.	50.	50.	50.	50.	82.	99.	50.	50.	50.	93.	11.	50.	50.	50.	99.	91.	50.	50.	50.	50.	50.	50.
9	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	50.	50.
10	50.	50.	50.	50.	98.	50.	50.	50.	50.	91.	50.	50.	50.	50.	0.	50.	50.	50.	50.	99.	50.	50.	50.	50.	50.
11	99.	50.	50.	50.	50.	94.	50.	50.	50.	50.	0.	50.	50.	50.	50.	0.	50.	50.	50.	50.	50.	50.	50.	50.	50.
12	50.	92.	50.	50.	50.	50.	96.	50.	50.	50.	50.	38.	50.	50.	50.	50.	0.	50.	50.	50.	50.	50.	50.	50.	50.
13	50.	50.	50.	50.	50.	50.	50.	0.	50.	50.	50.	50.	0.	50.	50.	50.	50.	0.	50.	50.	50.	50.	88.	50.	50.
14	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	99.	98.	50.	50.	50.	99.	98.	50.	50.	50.	50.	50.	50.
15	50.	50.	50.	50.	99.	50.	50.	50.	50.	23.	50.	50.	50.	50.	0.	50.	50.	50.	50.	0.	50.	50.	50.	50.	99.
16	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	6.	50.	50.	50.	50.	0.	50.	50.	50.	50.	98.	50.	50.	50.	50.
17	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	0.	50.	50.	50.	0.	0.	50.	50.	50.	50.	99.	50.	50.	50.
18	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	99.	0.	50.	50.	50.	0.	0.	50.	50.	50.	99.	0.	50.	50.
19	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	87.	99.	50.	50.	50.	50.	98.	50.
20	50.	50.	50.	50.	50.	50.	50.	50.	50.	86.	50.	50.	50.	50.	0.	50.	50.	50.	99.	0.	50.	50.	50.	50.	98.
21	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	50.	98.	50.	50.	50.	50.	99.	50.	50.	50.	50.
22	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	99.	99.	50.	50.	50.	99.	99.	50.	50.	50.
23	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	97.	50.	50.	50.	99.	99.	50.	50.
24	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	0.	50.	50.	50.	50.	99.	99.	50.
25	50.	50.	50.	50.	50.	50.	50.	50.	50.	11.	50.	50.	50.	50.	99.	50.	50.	50.	50.	97.	50.	50.	50.	99.	92.

Table 7

Weight Matrix Straight and Level Flight: Airspeed Control

Source Cell	Receiving Cell 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	99.	99.	50.	50.	50.	98.	28.	50.	50.	50.	99.	0.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	99.
2	50.	50.	99.	99.	50.	50.	50.	50.	99.	99.	50.	50.	0.	50.	50.	50.	50.	50.	99.	50.	50.	50.	0.	0.	50.
3	50.	50.	50.	50.	50.	50.	50.	50.	0.	50.	50.	50.	50.	0.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	50.
4	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	0.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
5	50.	50.	50.	50.	98.	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	75.	50.	50.	50.	50.	99.
6	98.	50.	50.	50.	50.	92.	0.	50.	50.	50.	98.	32.	50.	50.	50.	99.	99.	50.	50.	50.	50.	50.	50.	50.	50.
7	50.	31.	99.	50.	50.	50.	0.	0.	50.	50.	50.	95.	0.	50.	50.	50.	50.	99.	50.	50.	50.	50.	50.	50.	50.
8	50.	50.	0.	0.	50.	50.	50.	0.	0.	50.	50.	50.	30.	0.	50.	50.	50.	99.	50.	50.	50.	50.	50.	50.	50.
9	50.	50.	50.	50.	99.	50.	50.	50.	0.	0.	50.	50.	30.	0.	0.	50.	50.	50.	50.	98.	50.	50.	50.	50.	99.
10	50.	50.	50.	50.	99.	50.	50.	50.	50.	88.	50.	50.	50.	50.	88.	50.	50.	50.	50.	43.	50.	50.	50.	50.	99.
11	54.	50.	50.	50.	50.	92.	50.	50.	50.	50.	95.	99.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.
12	50.	99.	50.	50.	50.	50.	51.	29.	50.	50.	72.	78.	97.	50.	50.	0.	99.	50.	50.	50.	50.	50.	50.	50.	50.
13	50.	50.	50.	50.	50.	50.	36.	0.	36.	50.	50.	98.	0.	0.	50.	50.	36.	99.	50.	50.	50.	99.	99.	50.	50.
14	50.	50.	50.	50.	50.	50.	50.	50.	0.	6.	50.	50.	0.	0.	0.	50.	50.	99.	0.	50.	50.	50.	50.	50.	50.
15	50.	50.	50.	50.	50.	50.	50.	50.	50.	0.	50.	50.	50.	42.	0.	50.	50.	50.	99.	93.	50.	50.	50.	50.	99.
16	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	96.	50.	50.	50.	50.	98.	50.	50.	50.	50.	99.	50.	50.	50.	50.
17	50.	2.	50.	50.	50.	50.	98.	50.	50.	50.	99.	97.	50.	50.	50.	98.	99.	50.	50.	50.	99.	50.	50.	50.	50.
18	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	98.	98.	50.	50.	50.	97.	22.	50.	50.	50.	99.	50.	50.	50.
19	50.	50.	12.	50.	50.	50.	50.	50.	50.	50.	50.	50.	9.	99.	50.	50.	50.	97.	12.	50.	50.	50.	99.	50.	50.
20	50.	50.	50.	88.	88.	50.	50.	50.	88.	98.	50.	50.	50.	14.	93.	50.	50.	50.	98.	91.	50.	50.	50.	0.	98.
21	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.
22	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	50.
23	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	0.	99.	50.	50.	50.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.
24	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	0.	50.	50.	50.	0.	50.	50.	50.	50.	50.	50.	50.	50.
25	50.	50.	50.	50.	99.	50.	50.	50.	99.	50.	50.	50.	99.	50.	50.	50.	50.	99.	99.	99.	99.	99.	50.	50.	99.

Table 8

Weight Matrix Straight and Level Flight: Heading Control

	Receiving Cell																								
Source Cell	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0.	0.	50.	50.	50.	99.	99.	0.	50.	50.	99.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	96.
2	50.	0.	0.	0.	50.	50.	50.	0.	50.	50.	50.	50.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
3	50.	50.	50.	0.	99.	50.	50.	50.	99.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
4	50.	50.	50.	50.	0.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
5	50.	50.	50.	50.	0.	50.	50.	50.	50.	0.	50.	50.	50.	50.	92.	50.	50.	50.	50.	64.	50.	50.	50.	50.	0.
6	95.	0.	50.	50.	50.	83.	0.	50.	50.	50.	96.	0.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
7	50.	50.	50.	50.	50.	50.	94.	91.	50.	50.	50.	0.	0.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
8	50.	50.	49.	50.	50.	50.	50.	91.	42.	50.	50.	50.	94.	0.	50.	50.	50.	50.	50.	50.	50.	50.	0.	50.	50.
9	50.	50.	50.	50.	50.	50.	50.	50.	73.	99.	50.	50.	50.	32.	99.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
10	50.	50.	50.	50.	94.	50.	50.	50.	50.	98.	50.	50.	50.	50.	91.	50.	50.	50.	50.	98.	50.	50.	50.	50.	19.
11	50.	50.	50.	50.	50.	0.	0.	50.	50.	50.	0.	50.	50.	50.	50.	0.	50.	50.	50.	50.	99.	50.	50.	50.	50.
12	50.	50.	50.	50.	50.	0.	95.	0.	50.	50.	37.	0.	97.	50.	50.	50.	98.	50.	50.	50.	50.	0.	50.	50.	50.
13	50.	50.	50.	50.	50.	50.	50.	0.	99.	50.	50.	0.	21.	96.	50.	50.	0.	93.	50.	50.	50.	50.	99.	50.	50.
14	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	94.	0.	99.	50.	50.	0.	0.	50.	50.	50.	50.	50.	50.
15	50.	50.	50.	50.	38.	50.	50.	50.	50.	92.	50.	50.	50.	50.	57.	50.	50.	50.	50.	93.	50.	50.	50.	50.	97.
16	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	0.	50.	50.	50.	50.	96.	50.	50.	50.	50.	99.	50.	50.	50.	50.
17	50.	50.	50.	50.	50.	99.	50.	50.	50.	50.	0.	97.	50.	50.	50.	98.	98.	50.	50.	50.	50.	50.	50.	50.	50.
18	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	0.	0.	50.	50.	50.	98.	94.	50.	50.	50.	0.	50.	50.	50.
19	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	0.	99.	50.	50.	50.	72.	0.	50.	50.	50.	0.	50.	50.
20	50.	50.	50.	50.	98.	50.	50.	50.	50.	15.	50.	50.	50.	99.	0.	50.	50.	50.	99.	85.	50.	50.	50.	99.	98.
21	75.	50.	50.	50.	50.	50.	50.	50.	50.	50.	0.	50.	50.	50.	50.	94.	50.	50.	50.	50.	50.	50.	50.	50.	50.
22	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	98.	50.	50.	50.	50.	0.	99.	50.	50.	50.
23	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	50.	20.	97.	50.	50.	99.	34.	50.	50.	50.
24	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.
25	0.	50.	50.	50.	98.	50.	50.	50.	50.	99.	50.	50.	50.	50.	99.	50.	50.	50.	50.	93.	98.	50.	98.	98.	71.

Analysis 3

Purpose

To provide an initial estimate of the ability of score weights developed for one set of students (i.e., a training set consisting of students who passed and also students who failed subsequent training programs) to discriminate performance of another set of students (i.e., a test set consisting of students of both categories whose performance data was not included when developing the score weights). It must be noted that with the limited number of students' performance data available, it was not possible to determine the statistical significance of the test set performance evaluations; but the analysis provided an initial evaluation of the scoring system.

Method

Two students from each category, a total of four students, were selected at random and their performance data used for the training set. The training set consisted of Students 4935 and 20935 who passed the training course, and 8933 and 15933 who failed the training course. The two remaining students, one in each category (9935 passed, 20933 failed) were scored as the test set.

Results

Tables 2, 3, and 4 show the results of the test and training set scores. The results are marked "Score B" in the tables. Results for altitude control, Table 2, show that proper student class discrimination was achieved for the test students since Student 9935 was scored higher than any of the students in the failed category, and Student 20933 scored lower than any student in the passed category.

Turning now to the scores for airspeed control shown in Table 3, we find a similar result to that of altitude control: student class discrimination was achieved and the effect of using the two students' (9935, and 20933) flight data was similar. Scores for the remaining four students were very stable when comparing values of Score A to that of Score B. This suggests that common factors might exist in the flight data for each student class since using or not using one student's flight data did not appear to affect the scores much.

Finally, turning to heading control scores, shown in Table 4, we see that discrimination of student class was <u>not</u> achieved. There were several possible explanations for such a result:

1. Heading control was in some way different from altitude and airspeed control in straight and level flight (for instance, good heading control may be either very easy or very difficult in straight and level flight (SLF); therefore, heading control in SLF was not a good predictor of later flight training performance).

2. Heading control was not in some way different from altitude and airspeed control for purposes of predicting student capability to pass the subsequent initial rotary wing training. And the results obtained with altitude and airspeed control do not generalize for a larger student population.

The next analysis (4) was designed to investigate this question.

Comparison of student scores for the three variables under control reveals inconsistent ratings of individual students. For instance, Student 4935 ranked second in altitude control, third in airspeed control, and first in heading control. This suggests that there may be variations in the criteria students used in allocating their control effort to each of the three channels.

Analysis 4

Purpose

To determine the application of score weights to a larger student population by comparing the empirically derived scores to those produced from transition weights suggested by control theory.

Method

Knowledge of control theory permits identification of some cell transitions as "good" and therefore should be weighted high, and others as "poor" and should be weighted low. Figures 9 and 10 show all these transitions respectively. Scores were calculated using the control theory based weighting matrix for each student and each control channel, i.e., altitude, airspeed, and heading.

Results

Results of Analysis 4 are shown in Table 9. As with the empirically based score weights, discrimination of student pass/fail classification was achieved with altitude and airspeed control, but not with heading control. This is evidence that:

1. Students could be classified with regard to capability to pass the subsequent training program by observing their altitude and airspeed control ability in the PASS (Marco, Bull, Vidmar, & Shipley, 1979) simulation test program. However, recall that data analyzed were collected from different test sessions and this alone may account for the differences found here. Additional student data must be analyzed to resolve this issue.

2. There was something different about heading control that prevented discrimination of student pass/fail classification.

It should also be noted that the discrimination for altitude and airspeed control of pass/fail classification was not as good (i.e., scores not as separated) with the weights developed from control theory as with the empirically developed weights. This suggests that the empirically developed weights contain weights

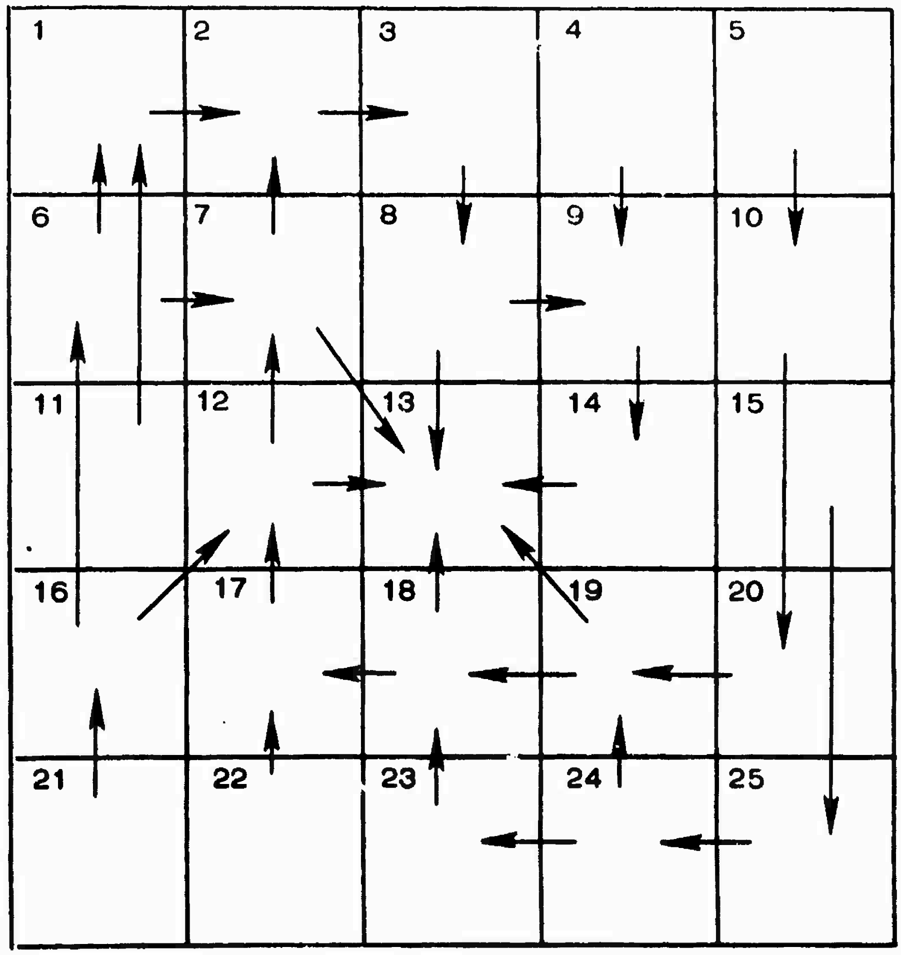


Figure 9. Cell Transitions Assigned a Score of 99.0

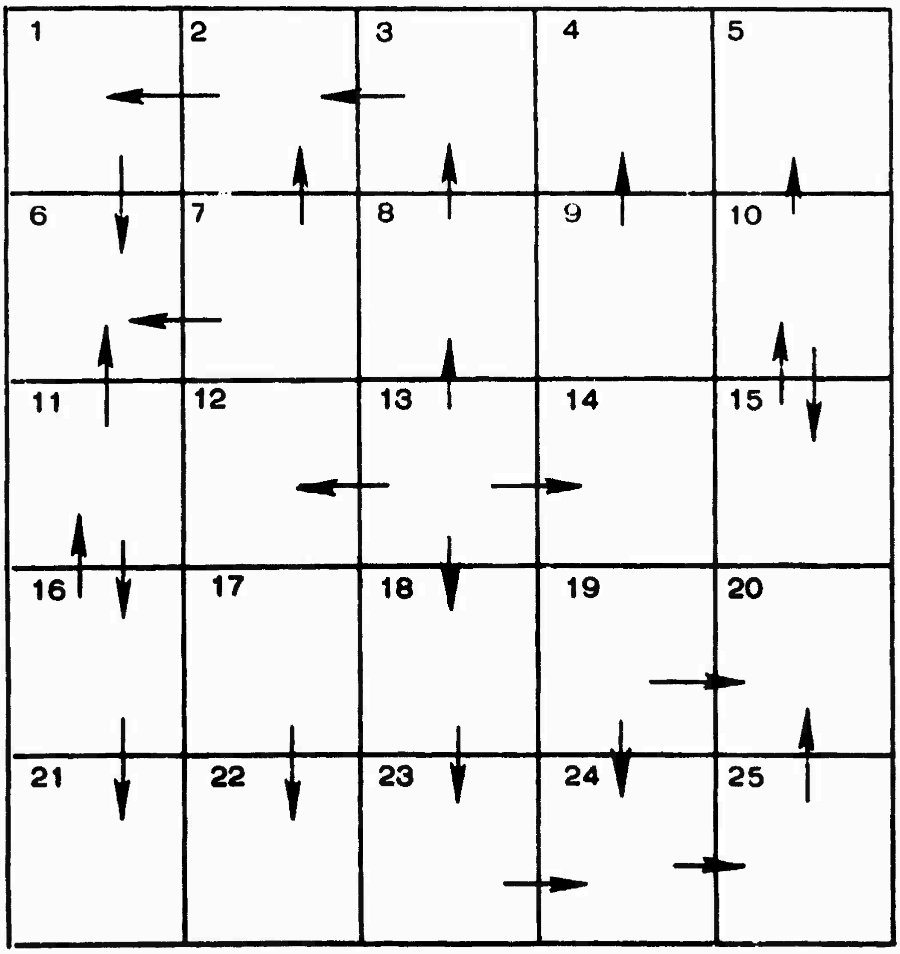


Figure 10. Cell Transitions Assigned a Score of 0.0

Table 9

Scores Using Weights Derived from Control Theory

Student	Pass/Fail	Altitude Control	Airspeed Control	Heading Control
4935	P	52.4	51.4	53.0
20935	P	51.0	50.4	48.8
9935	P	52.9	49.9	49.4
20933	F	47.9	49.7	47.9
8933	F	49.4	47.9	50.8
15933	F	50.2	49.5	49.3

of factors consistent with good theoretical control (which should permit extension of the results to a larger student population) plus weights of factors which may or may not apply only to discrimination of performance of the six students considered here. Thus, there may be additional factors to be weighted which would improve discrimination of student classification in a larger student population.

MISSION MODEL

Method of Approach

It must be noted that data as to how the actual near term Scout mission functions, and the operations and specifications of the actual equipment was not available at the time of this analysis. Operations and specification data were simply "imagined" by the authors for the analysis.

This section documents an analysis of the effects of operator errors on the detection and destruction of an enemy target. The process involved is shown in Figure 11. A Scout Helicopter in a masked position uses its mast sight to search for an enemy target. The operator detects a target. He then reduces the field of view, lines up the target on tha sight reticle and pushes a button to obtain laser ranging on the target. The result of the laser ranging is the calculation of the target XYZ coordinates. This information is communicated to another aircraft which is armed. The armed aircraft returns, via either an automatic link or voice link, the time of flight (TOF) data, which is manually entered into a terminal guidance system on the scout aircraft. When the missile is launched, the countdown is triggered (presumably manually in the scout). Near the end of the missile time of flight, the target is illuminated by a coded laser system on board the scout aircraft to assist with missile convergence on the target.

The coordinate system selected is shown in Figure 12. The scout aircraft is assumed to be at zero X and Y coordinates, and at elevation Z_D above the target. Further, the target is assumed to lie in the XY plane with X coordinate passing directly through the target. Thus, the correct target position as always has a zero Y coordinate value.

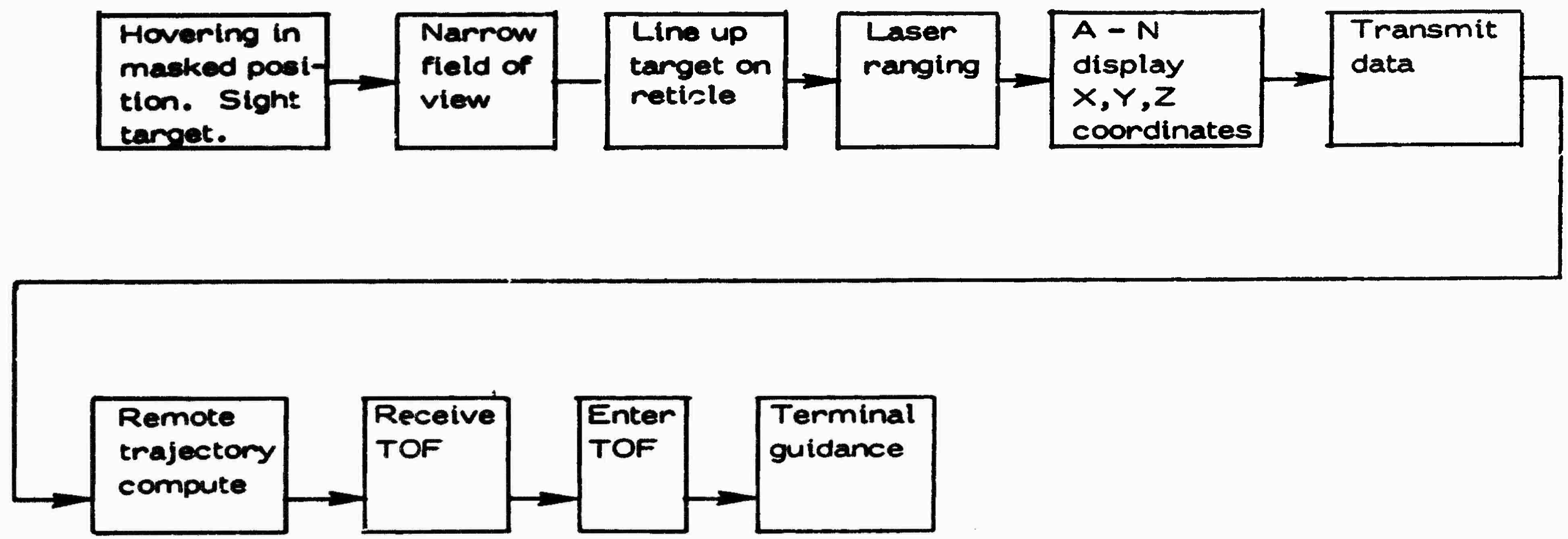


Figure 11. Hypothetical Scout Mission: Detect Target/Terminal Guidance

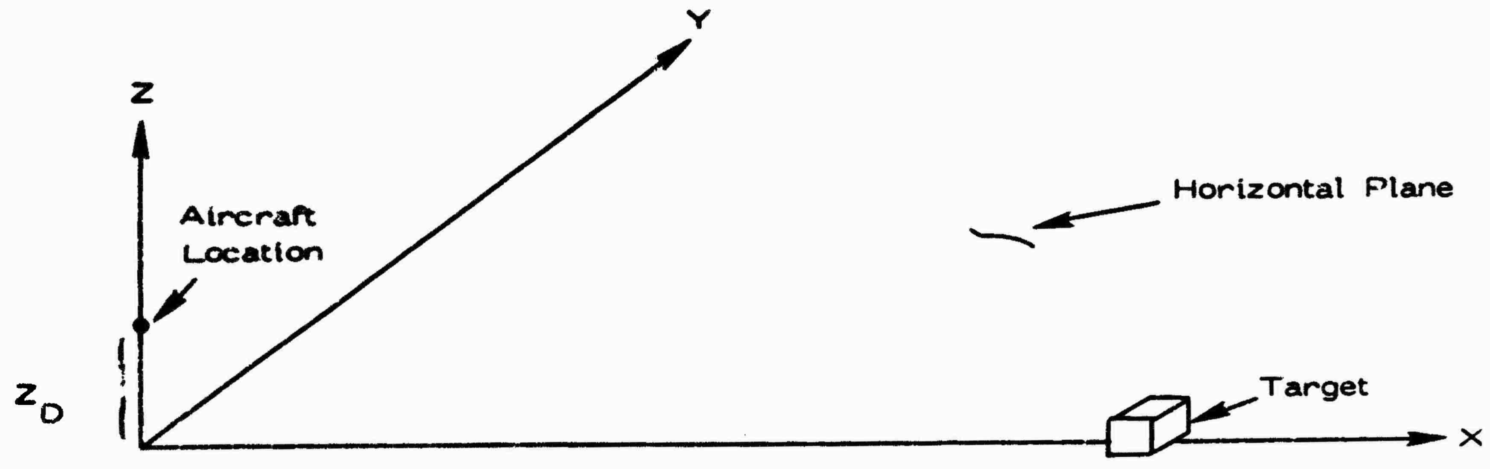


Figure 12. Coordinate System

Error Analysis

There are four sources of error represented in this simulation analysis. One is the drift of the navigation system which is assumed to be reset by a navigation fix at intervals of T hours. Thus, the location error is given by a simple linear function of the time-since-the-last-navigation-fix (T) as follows:

$$E_X = K_1 T \qquad (6)$$

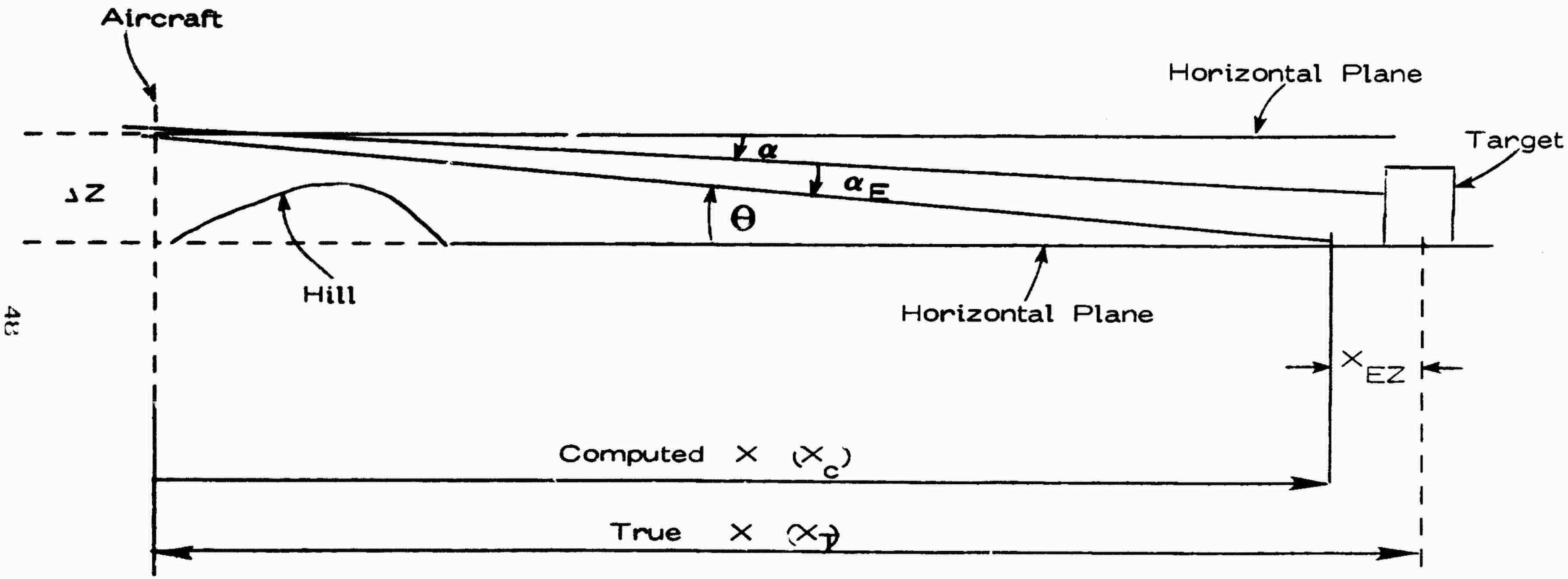
$$E_Y = K_2 T \qquad (7)$$

where K_1, K_2 are selected as random numbers from a normal distribution where $\mu = 0$ and σ^2 is equal to a constant (C).

The second type of error is an error in the angular position of the mast sight which can involve both an elevation error and an azimuth error. These error systems are shown in Figures 13 and 14 respectively. In calculating these errors it is assumed that due to the laser ranging, the range is calculated accurately and introduces no error into the system. The calculation of an elevation error involves the further assumption that a misdirected missile will impact on the horizontal plane containing the target. Thus, as shown in Figures 13 and 14, if the depression angle α is overestimated, the calculated X distance of a target will be shorter than its true value. Conversely, if the α value is underestimated, the calculated X value will exceed the true value. The equations for estimating the effect of the elevation error on X distance are as follows:

From Figure 13 it is seen that

$$\theta = \alpha + \alpha_E \qquad (8)$$



α = True Elevation Angle

α_E = Elevation Angle Error

Figure 13. Elevation Error

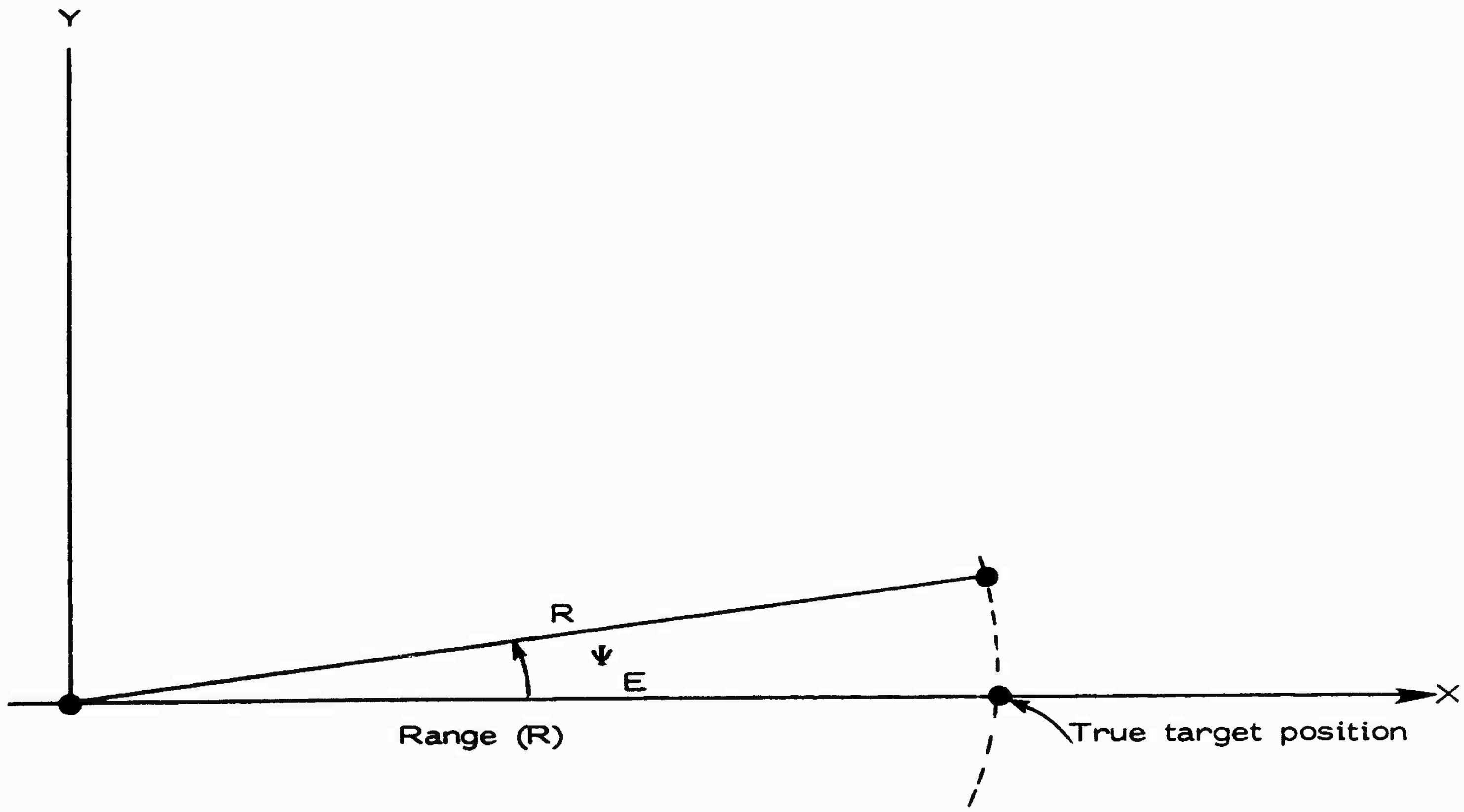


Figure 14. Azimuth Error

and

$$X_c = X_T - X_{EZ} \tag{9}$$

for large X_c and X_T with respect to ΔZ

$$\Delta Z \simeq X_c \sin\theta = X_c \sin(\alpha + \alpha_E) \tag{10}$$

$$\Delta Z \simeq X_T \sin\alpha$$

but

$$\sin(\alpha + \alpha_E) = \sin(\alpha)\cos(\alpha_E) + \tag{11}$$

$$\cos(\alpha)\sin(\alpha_E)$$

and by substitution

$$X_T \sin\alpha \quad (X_T - X_{EZ}) \ (\sin(\alpha)\cos(\alpha_E) + \cos(\alpha) \tag{12}$$

$$\sin(\alpha_E))$$

or solving for X_{EZ}

$$X_{EZ} \simeq X_T \left[1 - \frac{\sin\alpha}{(\sin\alpha\cos\alpha_E + \cos\alpha\sin\alpha_E)}\right] \tag{13}$$

but if α_E is small, then $\sin\alpha_E$ is small and

$$X_{EZ} \simeq X_T \left[1 - \frac{1}{\cos\alpha_E}\right] \tag{14}$$

The third type of error which is a data entry error is represented in two steps. First, a probability is assigned, which is the probability that a data entry error will occur, and in any particular simulation trial if an error occurs then the amount of the error is selected as a random number from a uniform distribution with a mean of zero and a specified range. Ranges for the errors in the X coordinate, Y coordinate, and Z coordinate are established independently and are given in subsequent tables.

The entry in the time of flight error which is the fourth type of error, is treated much the same as a data entry error, i.e., a probability is assigned which is the probability that an error occurs on any particular simulation run. If it is determined that an error has occurred, the amount of the error is taken as a random number selected from a uniform distribution with a mean of zero and a specified range. The effect of a data entry error is taken in a very simple form as shown in Figure 15. In the figure the effect of a time of flight (TOF) entry error is a multiplicative factor D. D equals .9 given there is no TOF error. D is reduced linearly to zero when the TOF entry error is equal to or greater than 5 seconds (either early or late).

The error effects discussed previously are summarized by the following equations:

$$X_e = K_1 T + R \cos \Psi_E + D_{EX} + X_{EZ} \tag{15}$$

$$Y_e = K_2 T + R \sin \Psi_E + D_{EY} \tag{16}$$

where $K_1 T$ is the effect of navigation drift since last time of fix, $(R \cos (\Psi_E))$ is the effect of an azimuth measurement error, X_{EZ} is the effect of an elevation measurement error and D_{EX} is the data entry error.

The Y coordinate has a similar set of terms but does not include a term for the effect of elevation error. Since it is assumed that the missile detonates upon impact, and that the horizontal plane contains the target, no error in the Z axis arises and thus the Z error is ignored.

The missile error measured as a radius from the target is converted into probability of kill (P_K' D) by the function shown in Figure 16. The total probability of kill (P_K) is given by:

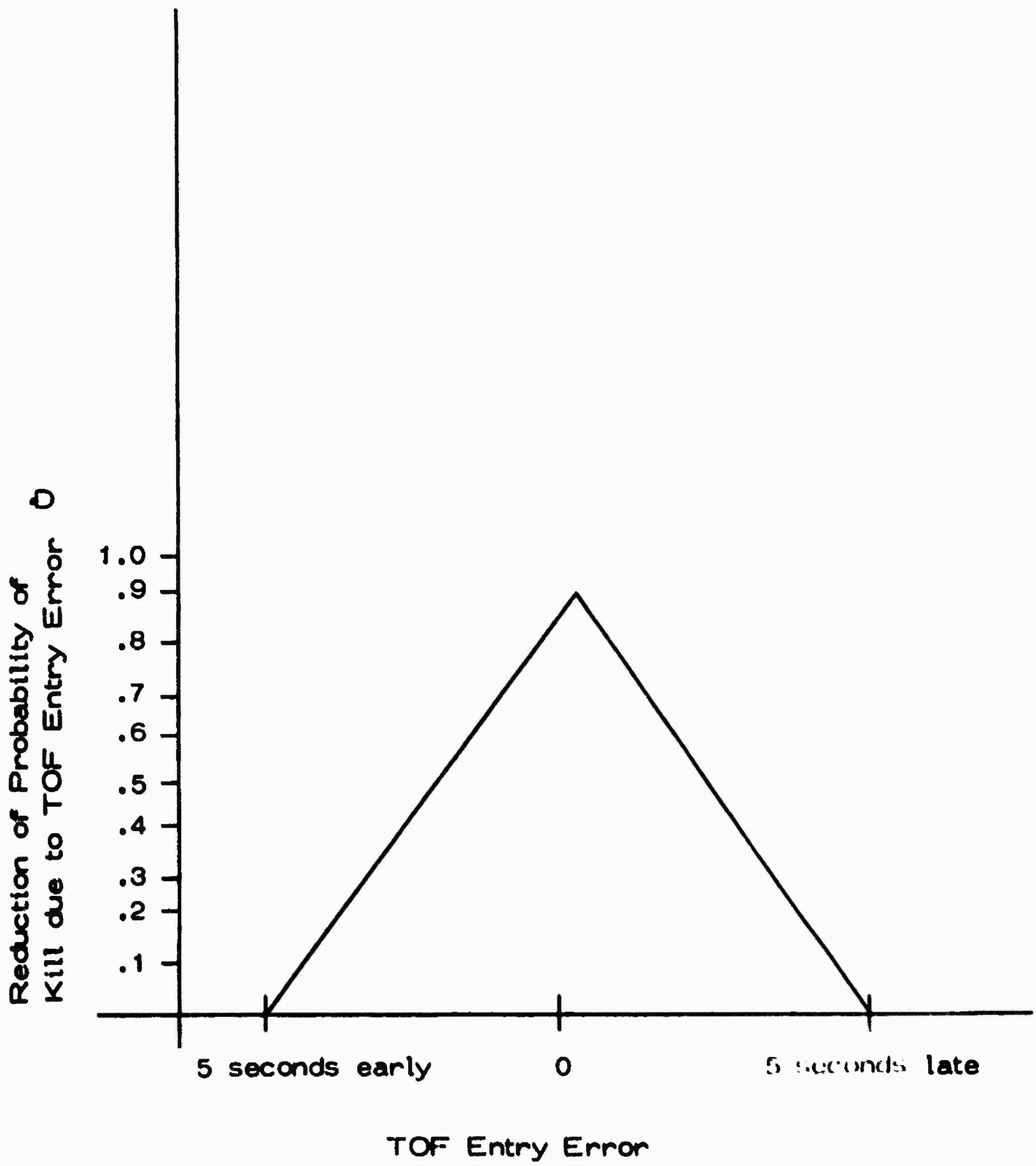


Figure 15. Effect of TOF Entry Error

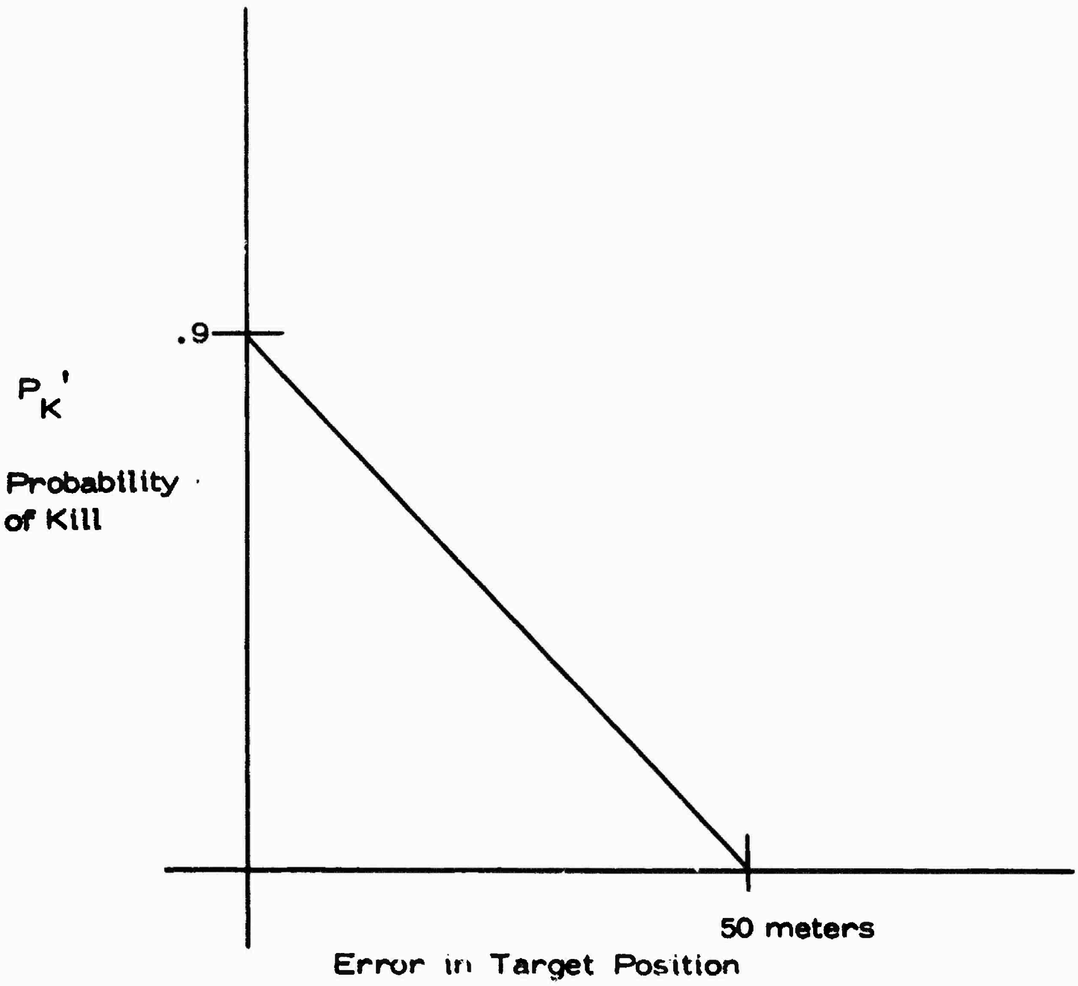


Figure 16. Probability of Kill Due to Target Position Calculation Error

$$P_K = P_K' \; D. \tag{17}$$

Simulation

A simulation has been conducted using the equations described above. This simulation is a Monte Carlo simulation with 10,000 runs per trial to determine the probability of kill. The program used for this simulation, written in FORTRAN IV, is listed in Appendix D.

Two series of trials were conducted. One series dealt with variations in each one of the variables affecting a probability of kill but with mean heading error set to zero. The data for the first series are listed in Table 10 where Item #3 is used as a base-line data set. On each successive run one of the variables of interest is changed. Note that in Table 10 four variables are changed: time since last navigation fix (time since true), the standard deviation of the azimuth and elevation errors, probability of data entry error, and probability of a time of flight error. Data plots showing the results of the simulation are listed in Figures 17, 18, 19, and 20.

The second simulation series used the base-line data for the four variables mentioned above but with mean heading error ranging from 0 error to 5° error in 1° steps. Figure 21 is a plot of probability of kill as a function of heading error.

CONCLUSIONS: ANALYSIS MODEL

The reader is cautioned that these results (stated in Conclusions 2, 3, 4, 5, and 6) are tentative because of the limited data set used and because other factors related to differences in maneuvers from which the data was taken may fully explain these results in terms of other factors. Additional student data must be analyzed to permit an adequate statistical analysis.

Table 10

Near Term Scout Mission Data

Series #1

Run	Variable	Value
1	Time Since True	0.125
2	"	0.25
3	"	0.50
4	"	0.75
5	"	0.875
6	σ^2 for Ψ_E, τ_E	.00003
7	"	.00003
3	"	.003
8	"	.03
9	"	.3
10	P (Data Entry Error)	.01
11	"	.05
3	"	.10
12	"	.15
13	"	.19
14	P (Time of Flight Error)	.01
15	"	.05
3	"	.10
16	"	.15
17	"	.19

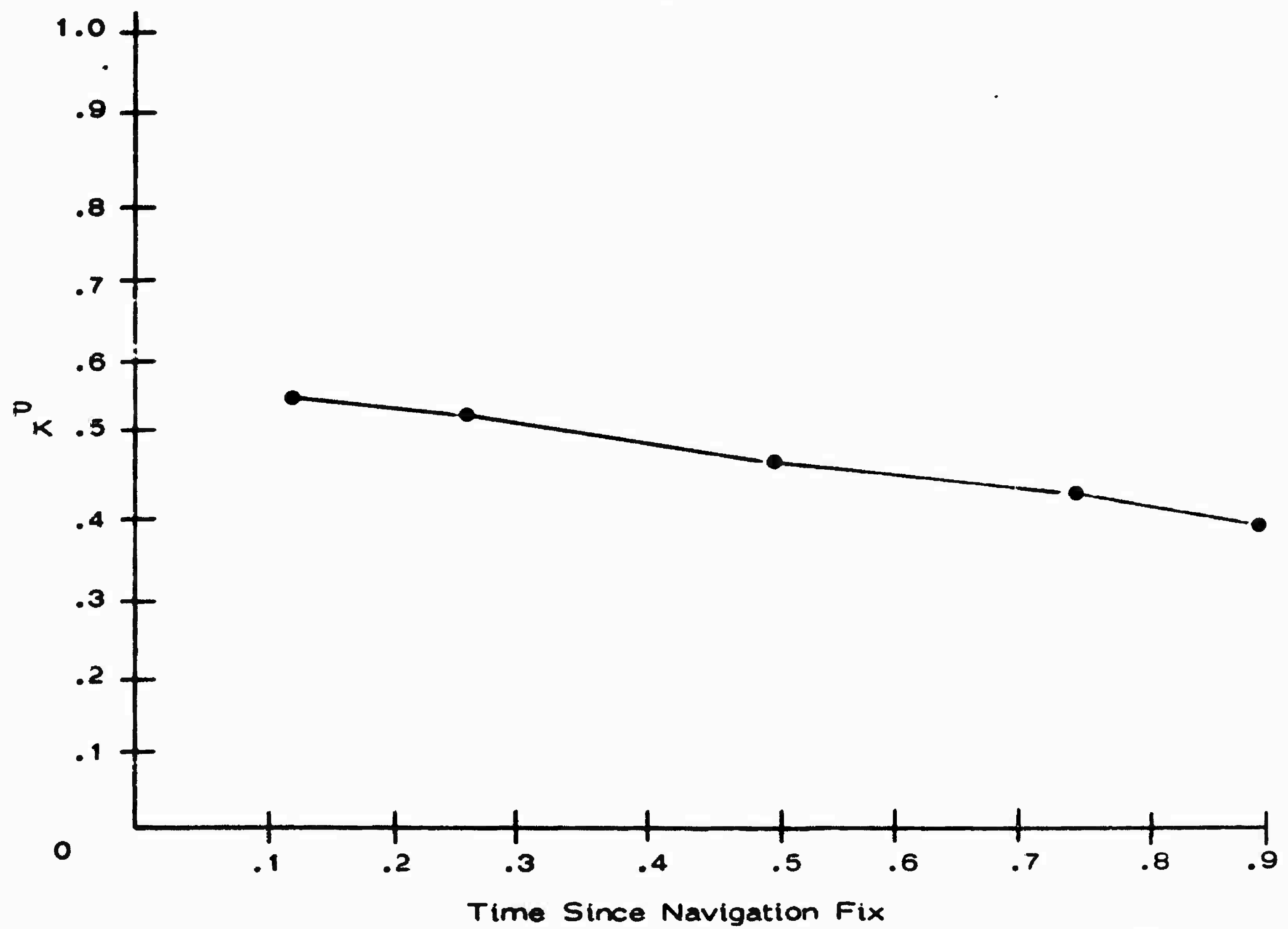


Figure 17. Probability of Kill vs. Time since Navigation Fix

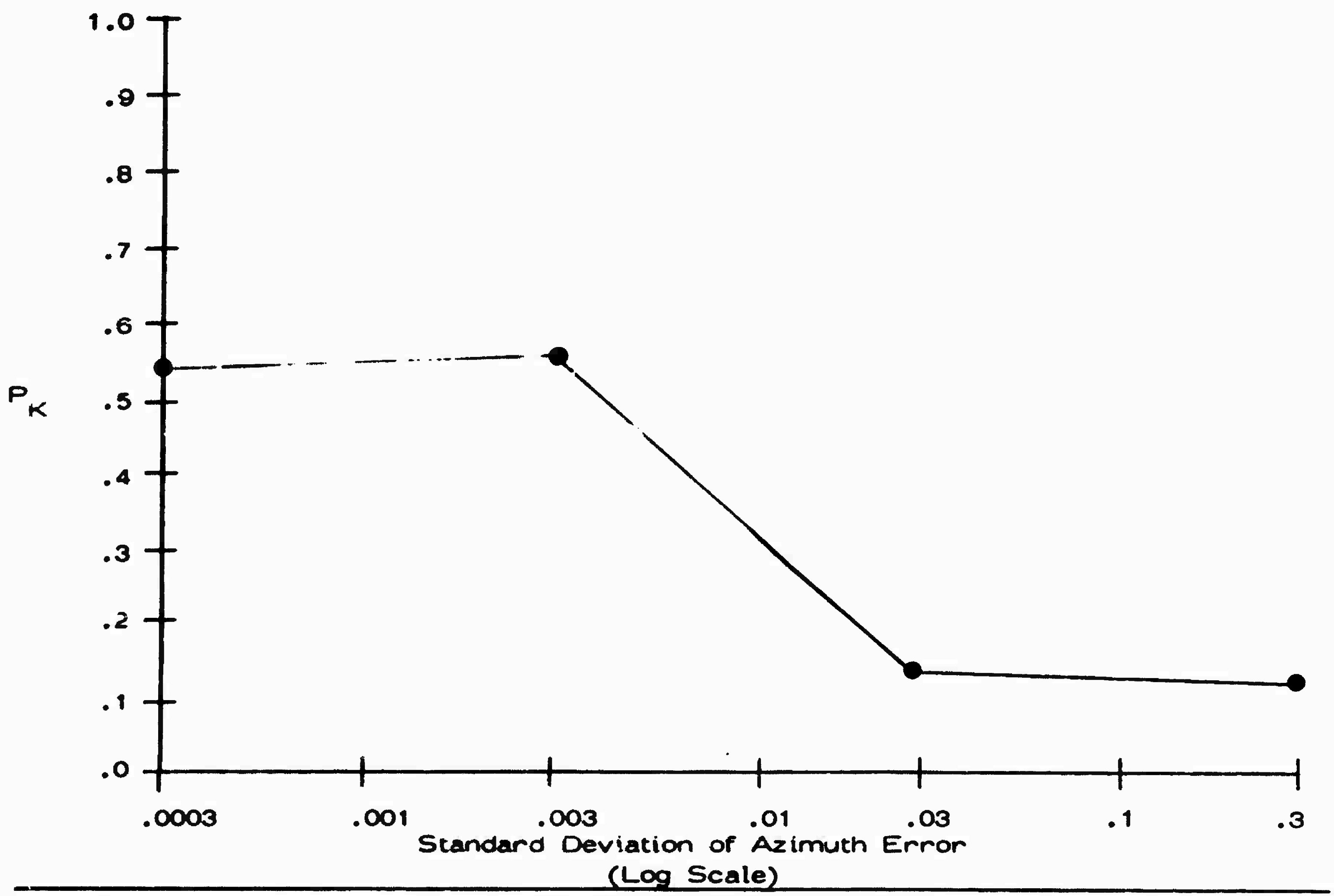


Figure 18. Probability of Kill vs. Standard Deviation of Azimuth

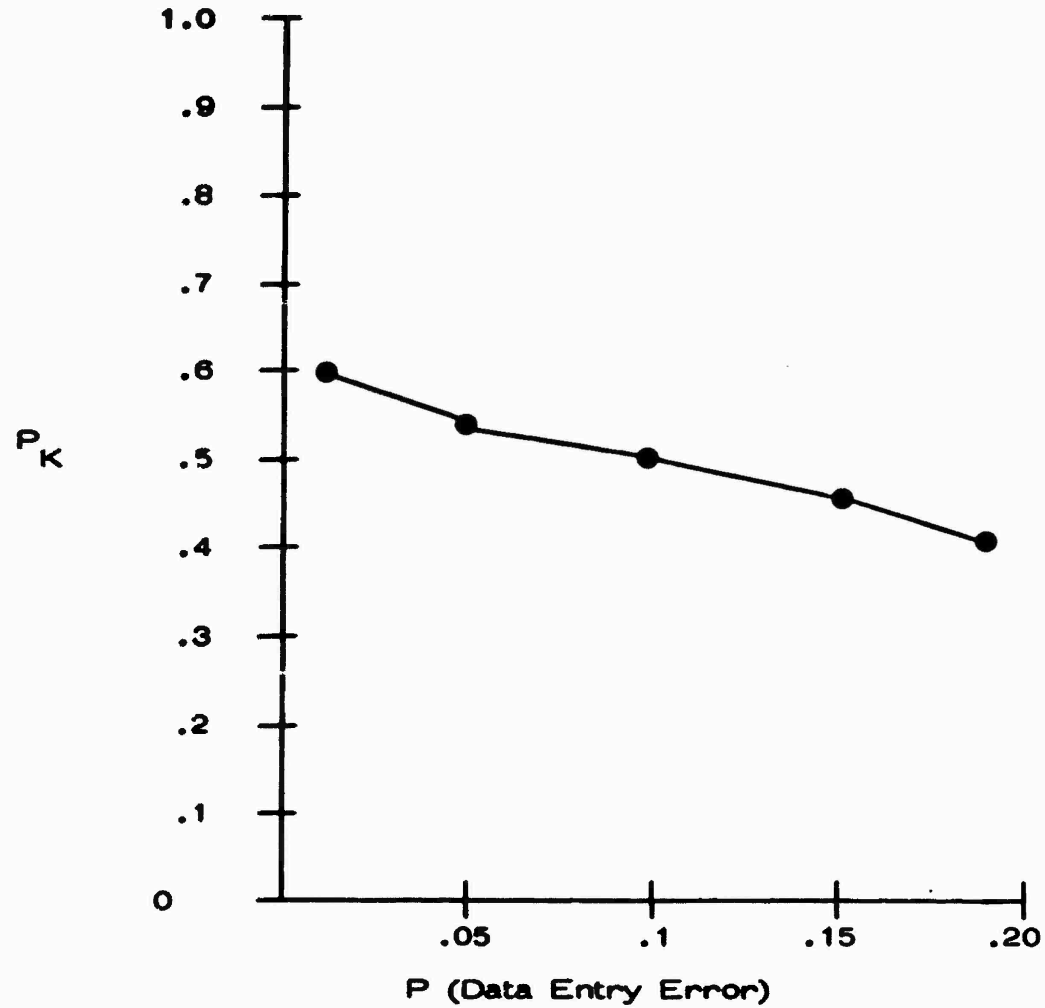


Figure 19. Probability of Kill vs. Probability of Data Entry Error

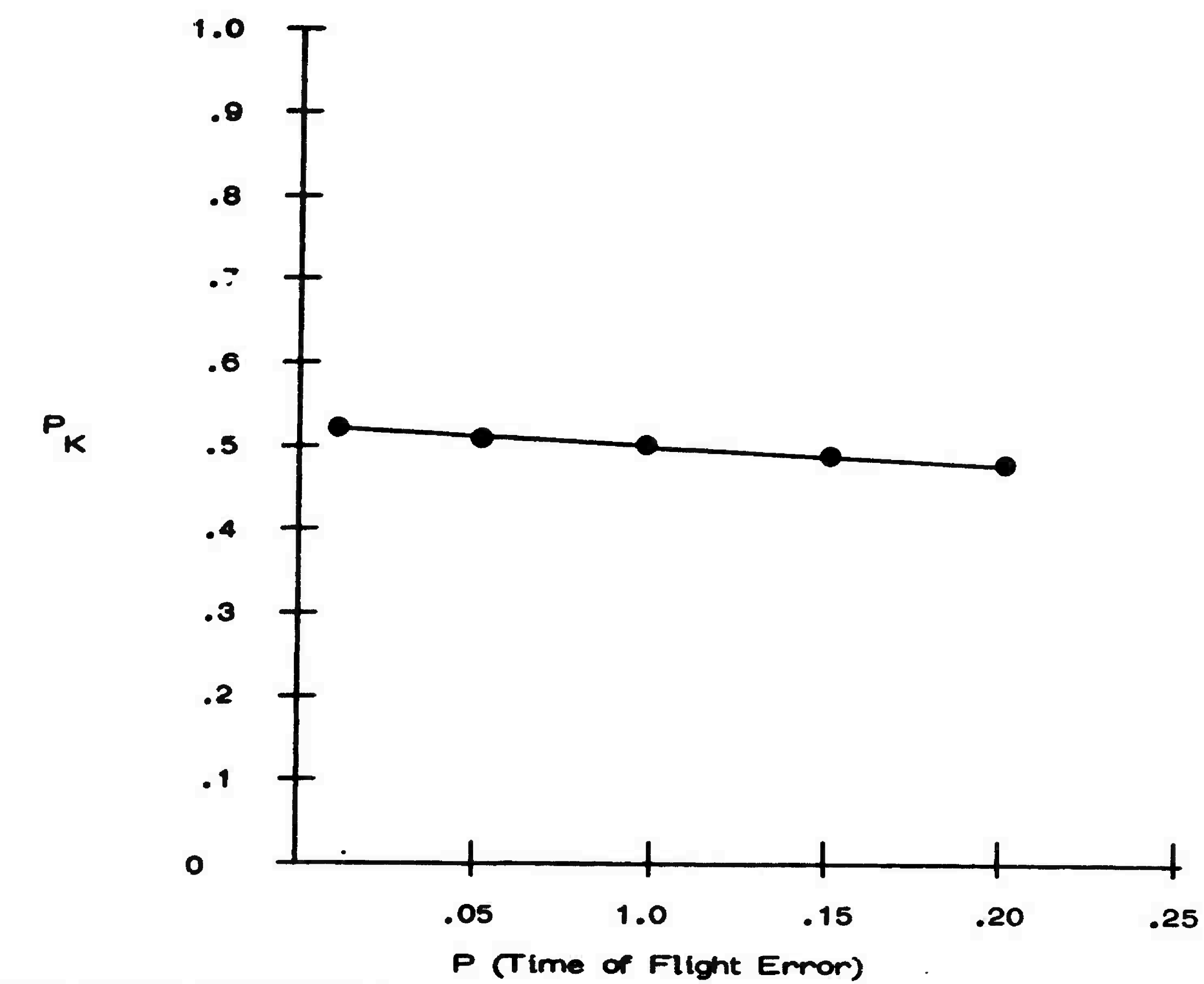


Figure 20. Probability of Kill vs. Probability of Time of Flight Error

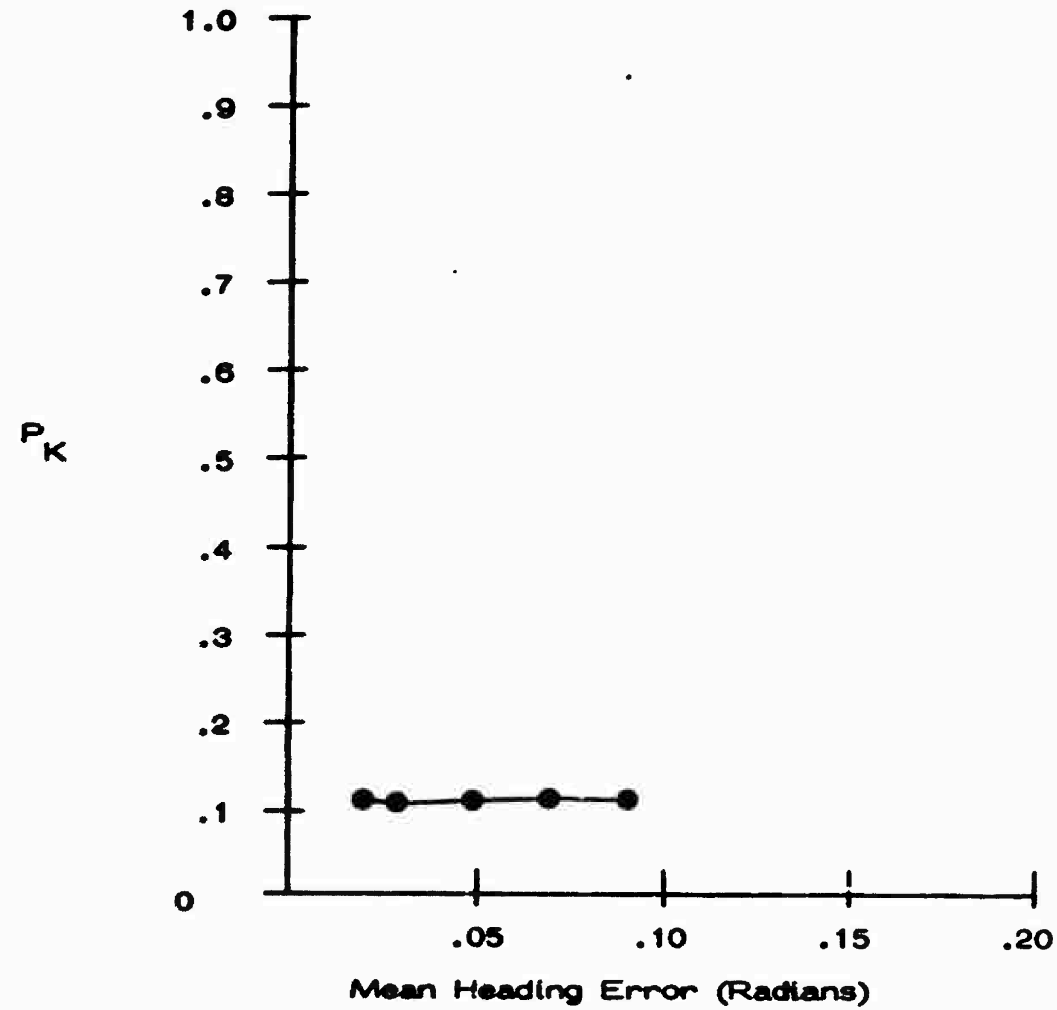


Figure 21. Probability of Kill vs. Mean Heading Error

However, based on the results of the four analyses at the present time, we conclude the following:

1. The method for combining performance data for each group of students and the method for calculating the transition weighting factors using the WTMAT program appears to be functioning as desired. A set of weighting is produced that discriminates the two groups of students based on the limited data available.

2. Altitude and air speed control in straight and level flight are potential discriminators of the success of students in subsequent flight training programs.

3. Because of the stability of the student scores in air speed control, when score weights were generated both with and without flight data from students selected at random, analysis of air speed control may lead to a reliable prediction of student flight training performance.

4. Heading control, at least in straight and level flight, does not appear to be a good predictor of a student's ability to perform well in flight training programs.

5. The cell transitions associated with poor (and also good) performance can be identified with the phase plane analysis. This information might be translated into aids for students that do get into the flight training program.

6. The "time-in-tolerance" (i.e., within specified error and error rate tolerance, such as in Cell 13) is apparently not a good performance discrimination factor. This result may be surprising since time-

in-tolerance is often suggested as a score factor. However, this result may be a general result since it was noted previously in a similar analysis but in a totally different flight environment (Connelly & Loental, 1974). Also, "time-in-tolerance" is cited by Poulten (1974) as a measure to be avoided in manual control systems because "in tolerance" condition can be achieved in many ways in addition to good control policies.

7. Success in scoring students whose flight data was not included when developing the score weights (i.e., the training set), and perhaps even more important, the similarity of scores using empirically developed weights with scores using weights developed from control theory, suggests that a "universal" (i.e., one that extends to a larger set of students) score weighting system might exist.

8. Empirically derived weights apparently contain weighting of factors consistent with those developed with control theory, plus additional factors which may or may not extend to a larger group of students.

RECOMMENDATIONS: ANALYSIS MODEL

There are many analyses that could not be performed due to time and funding limitations, but based on the results reported here, the following minimal set up analyses are recommended:

1. Comparison of empirically derived score weightings for altitude, airspeed, heading control, and weightings developed from the control theory should be extended. These comparisons should be made in segments of straight and level flight (as

the student gains more experience), and in other flight maneuvers, turns, climbs, dives, acceleration, deceleration, and VOR tracking. Further, these analyses should be conducted using additional student flight data.

2. A search for a universal score weighting matrix should be extended based on the additional analysis just described.

3. Particular attention should be given to weightings based on assymetrical and non-linear control characteristics (i.e., reduction of large errors vs. small errors and favoring of positive errors over negative errors, or vice versa). The purpose of this analysis is to determine whether or not linear pilot control models and linear analysis models can be appropriately applied to these flight performance measurement problems.

CONCLUSIONS: MISSION MODEL

Based on the results obtained in the analysis and simulation of a mission, we came to the following conclusions:

1. It is possible to provide an analysis and supporting simulation to transform parameters representing human operator skills (including manual, cognitive, and interactive skills) into their effects on mission performance. It must be recognized, however, that specific data on how these systems actually perform were not available and that the minimal results should not be considered as necessarily representative of any real world system.

2. The next logical step is to determine the actual human performance parameter values

and range of parameter values by obtaining experiment data using a validated detailed analysis method, or obtained from appropriate literature.

RECOMMENDATIONS: MISSION MODEL

The following recommendations are made relative to the mission model:

1. Additional mission models should be constructed so that a more complete set of mission tasks could be analyzed and simulated.

2. The human operator tasks required to perform these missions should be identified, and data developed on the parameters of task performance. (These parameters should include time to complete tasks as well as the measurement of the quality of the task given completion.)

3. The systematic program for the collection of data from all sources and the development of a performance handbook should be established. The handbook should be prepared and published to support design and evaluation of equipment for human operators.

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APPENDIX A

COMPUTATIONAL PLANS

COMPUTATIONAL PLANS

Processing of data for Student 4935 will be used to illustrate the analysis method shown in Figures A2 through A9. The coding system for naming files is given in Figure A1. Referring to Figure A2, File A491S1 contains Start/Stop points, error and error rate means for heading control in straight and level flight. File F4935 contains flight data for Student 4935. Student 4935 also has flight data located in a second file, B4935, and the Start/Stop points, error and error rate means for that flight data are located in A491S2

Using Program PHAN 3, data files A491S1, and F4935 are read and a cell frequency count file, H491C1 is produced. In a similar procedure, data in File A491S2 and B4935 are also read by Program PHAN 3 which produces a second count file, H491C2.

Program PHAN 5 is used to combine the two count files, H491C1 and H491C2, into a summary count file, H491C3, containing all the flight data for Student 4935.

Program PHAN 4 is used to convert Count File H491C3 into a transition file, H491T3, representing all transition probabilities for Student 4935 for heading control in straight and level flight. The summary count file, H491C3, is combined with H201C3 and H991C3 which are count files for Students 4935, 20935, and 9935 respectively. Using PHAN 5, the three count files are combined to produce HPC1. HPC1 represents cell transition counts for the three students who passed the subsequent training course. PHAN 4 is used again to convert the count file HPC1 into a transition file, HPT1.

As shown in Figure A6, Transition Files HPT1 and HFT1 were concatenated with the EDIT program to form file HPFT1. Also, target scores of 80. and 20. are included in File HPFT1 for students who passed or failed respectively, in the subsequent program.

Program WTMAT reads HPFT1, the input file, and produces HPFW1, the output file. HPFW1 is a score weight matrix. File HPFW1 is read by the SCORE program and the transition files for each student to give him/her scores and the probability of cell usage.

Example A491S1

1st Digit		2nd & 3rd Digits	
A	Altitude	99	Student 9935
H	Heading	20	Student 20935
S	Airspeed	15	Student 15933
R	Rate of Climb	89	Student 8933
		49	Student 4935
		21	Student 20933

4th Digit		5th Digit	
1	Straight Level	S	Start, Stop, Means
2	Right Turn	C	Count File
3	Left Turn	T	Transition File
4	Normal Climb		
5	Normal Descent		
6	Deacceleration		
7	Acceleration		

6th Digit

A number to distinguish among files with the same first five digits

Figure A1. File Codes

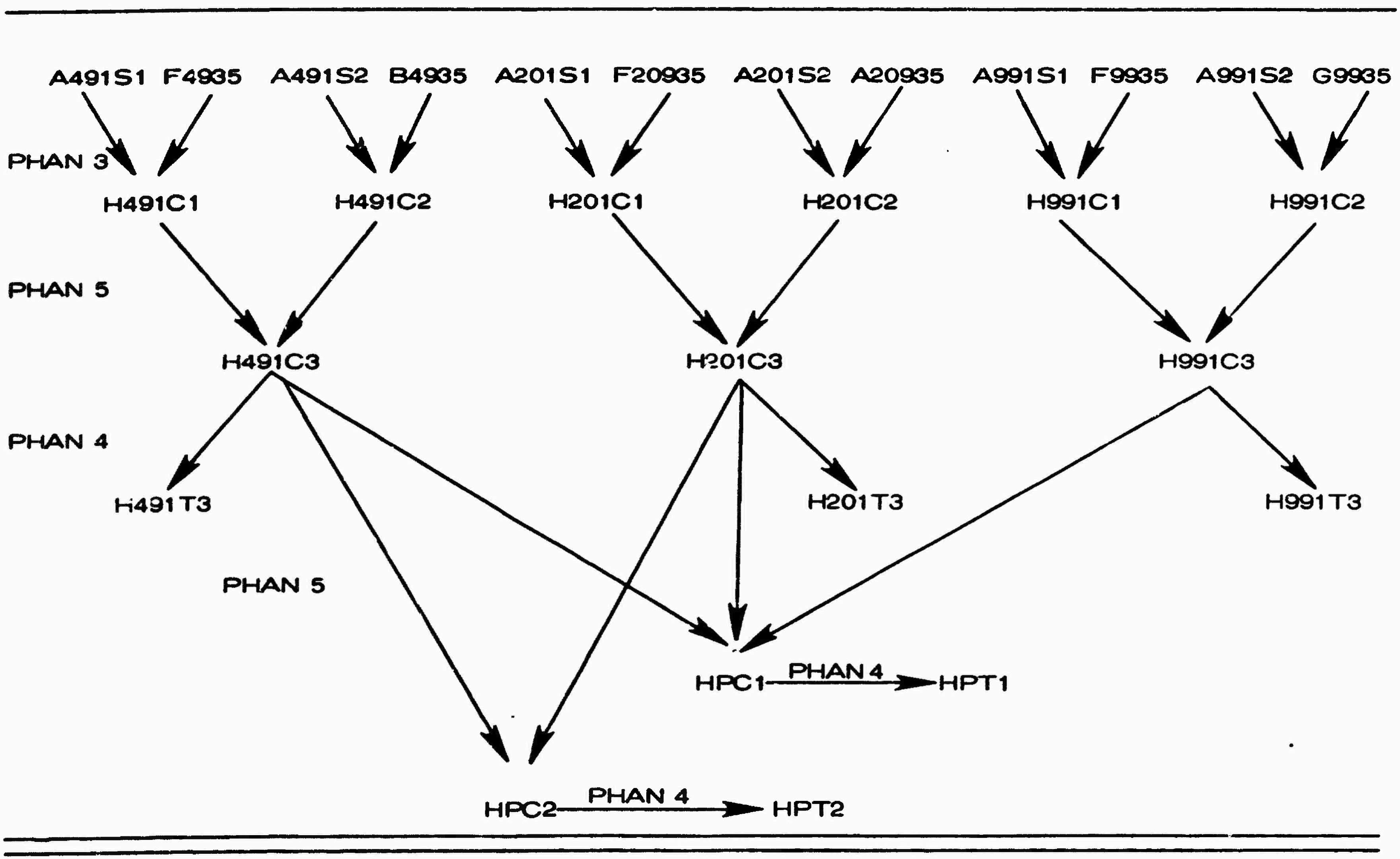

Figure A2. Computational Plan - Heading

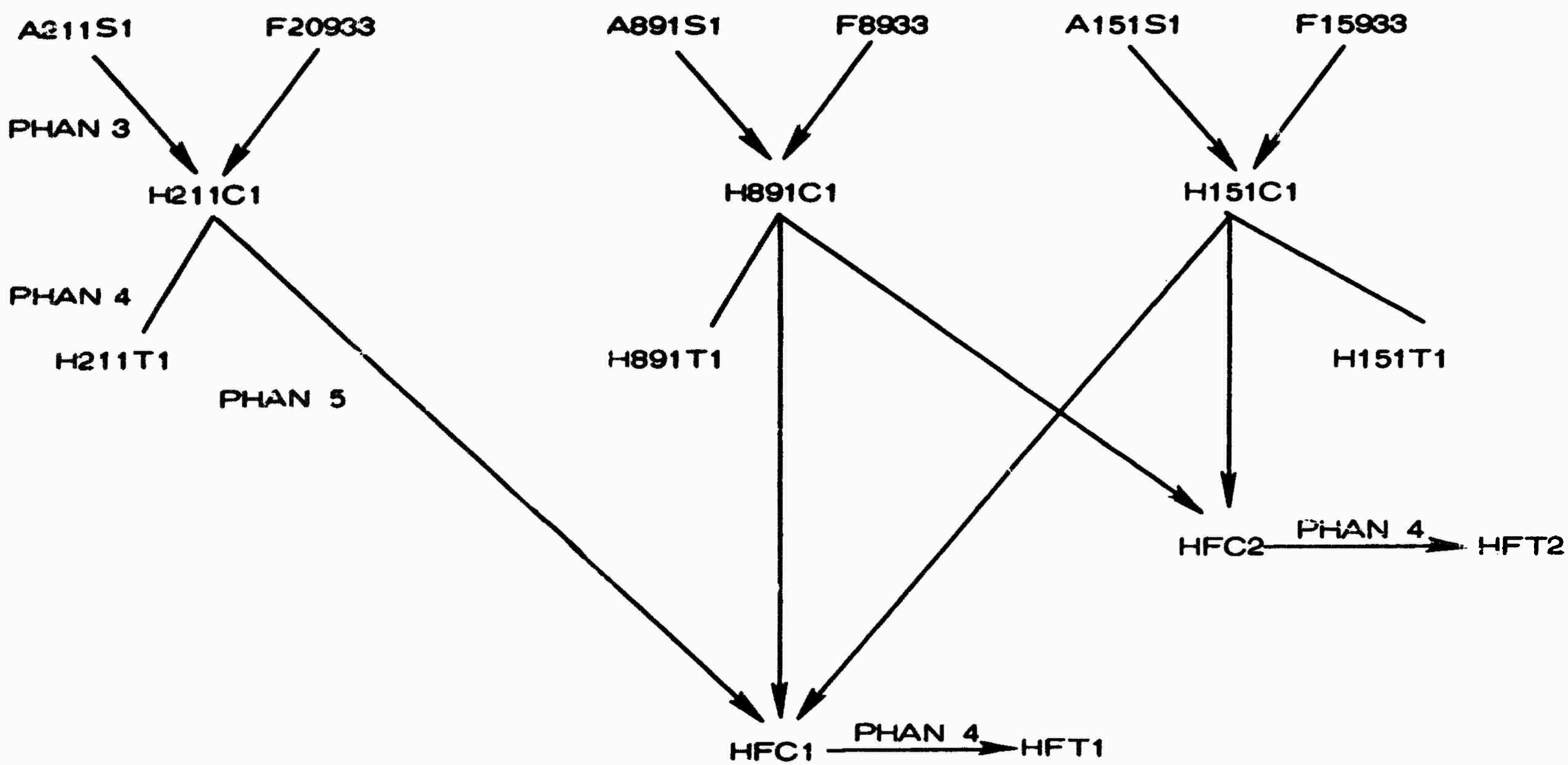

Figure A3. Computational Plan - Heading

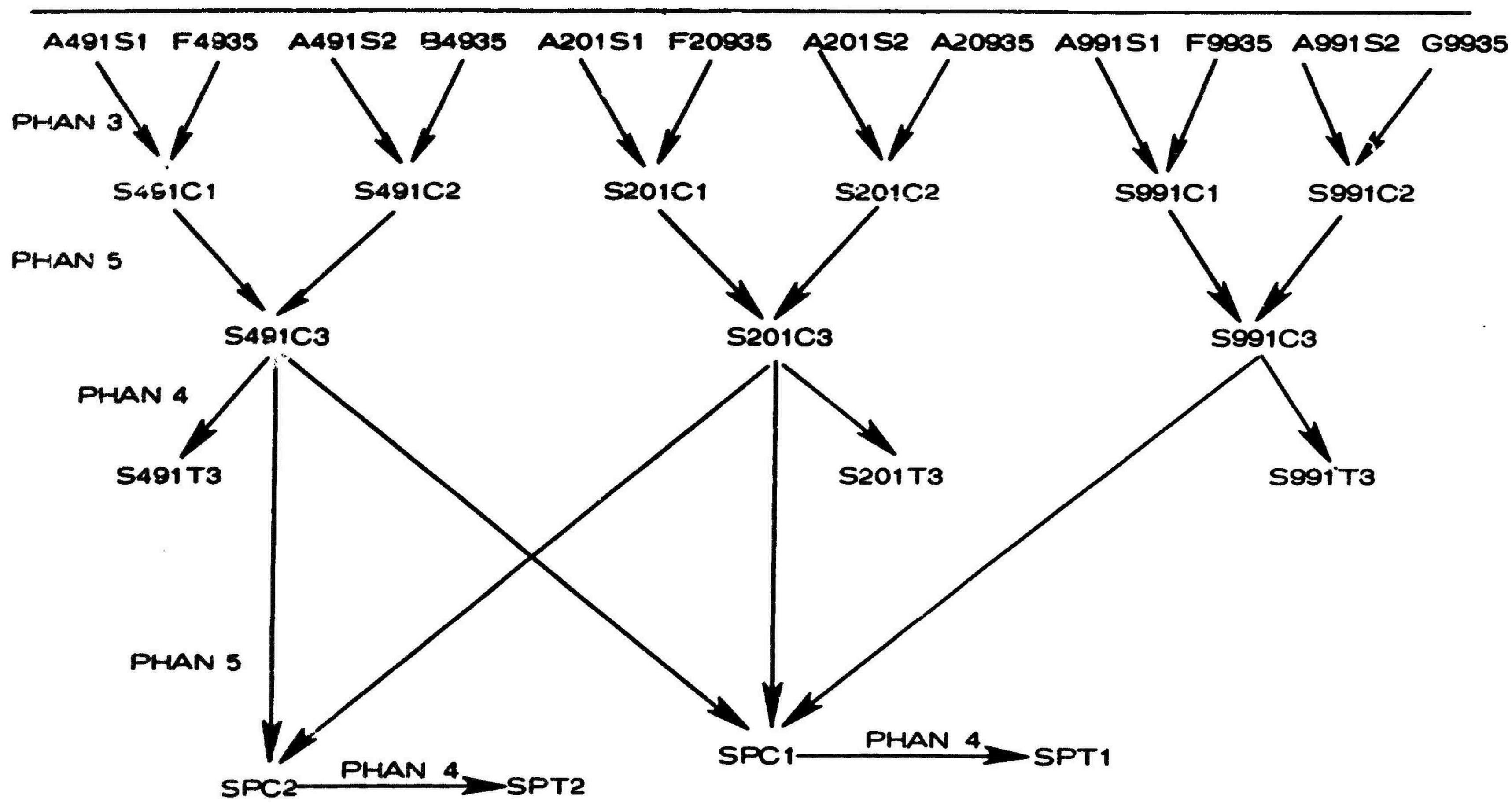

Figure A4. Computational Plan - Airspeed

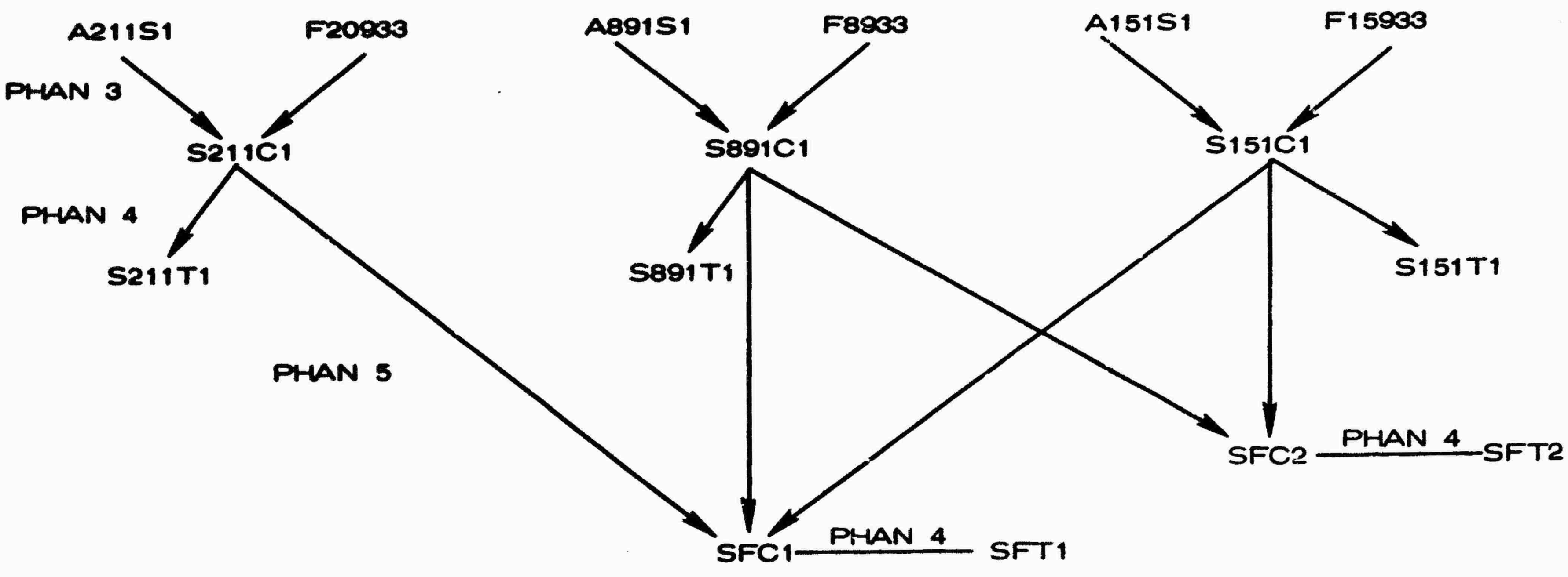

Figure A5. Computational Plan - Airspeed

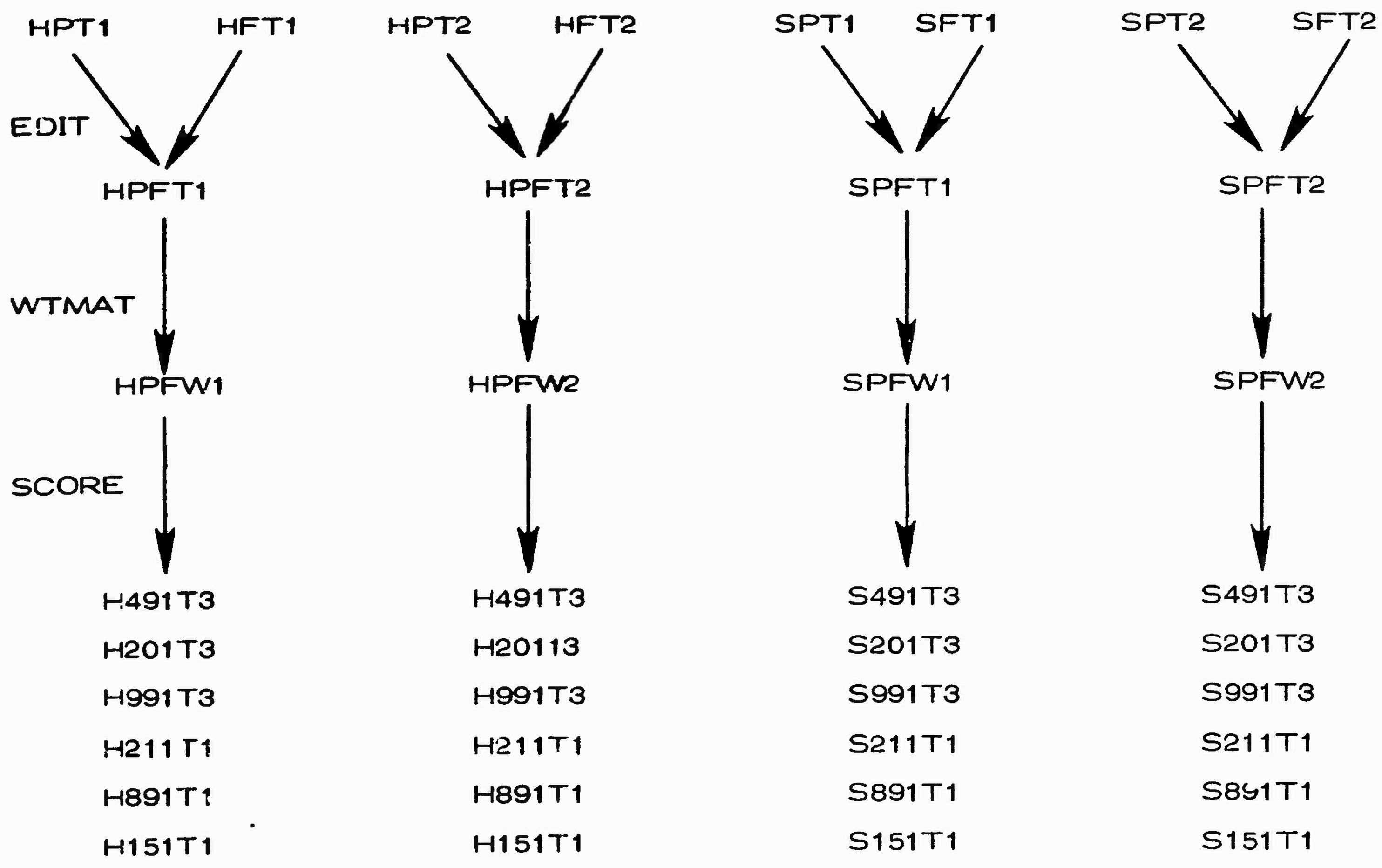

Figure A6. Computational Plan - Score

Heading/Airspeed

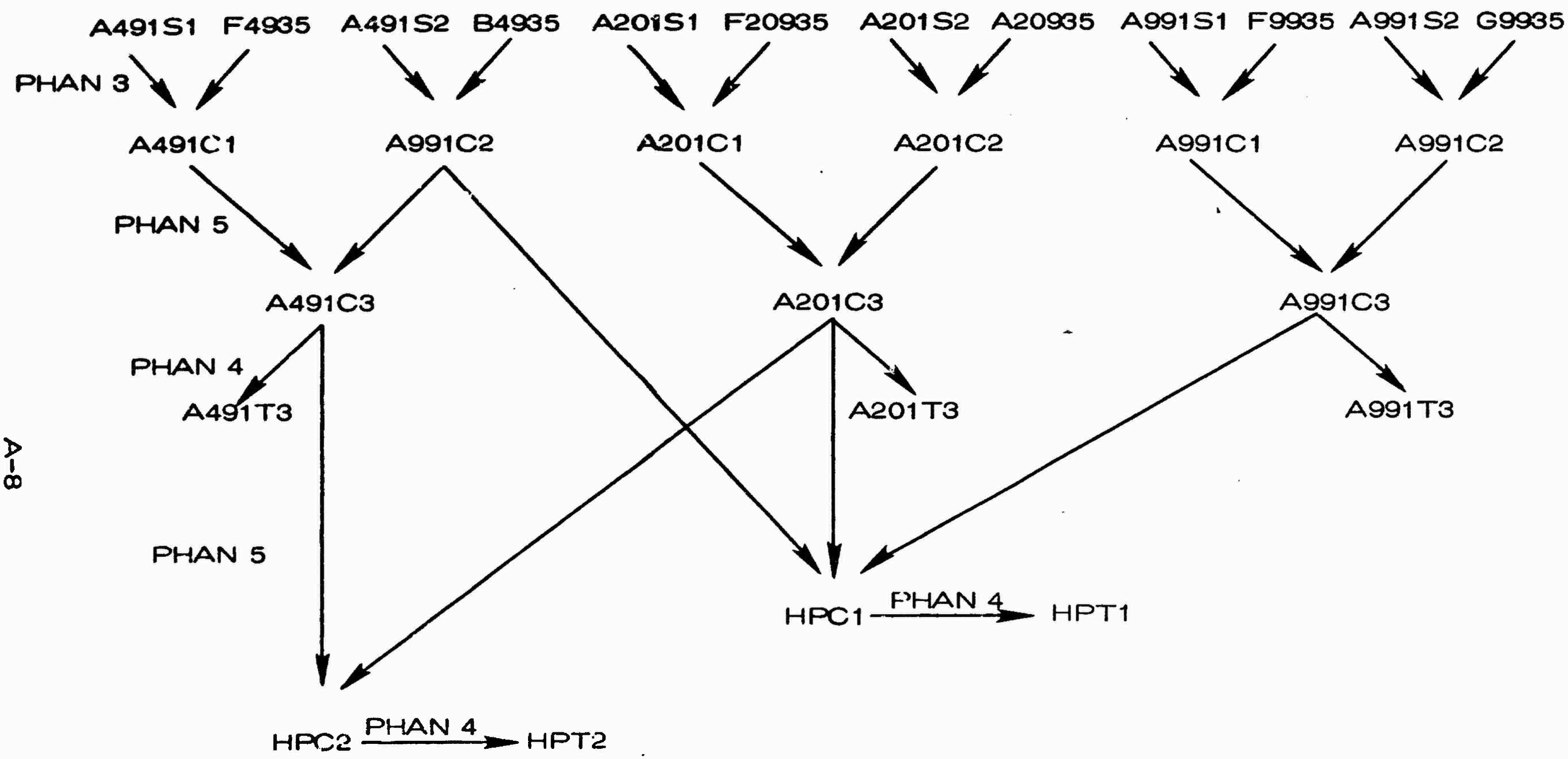

Figure A7. Computational Plan - Altitude

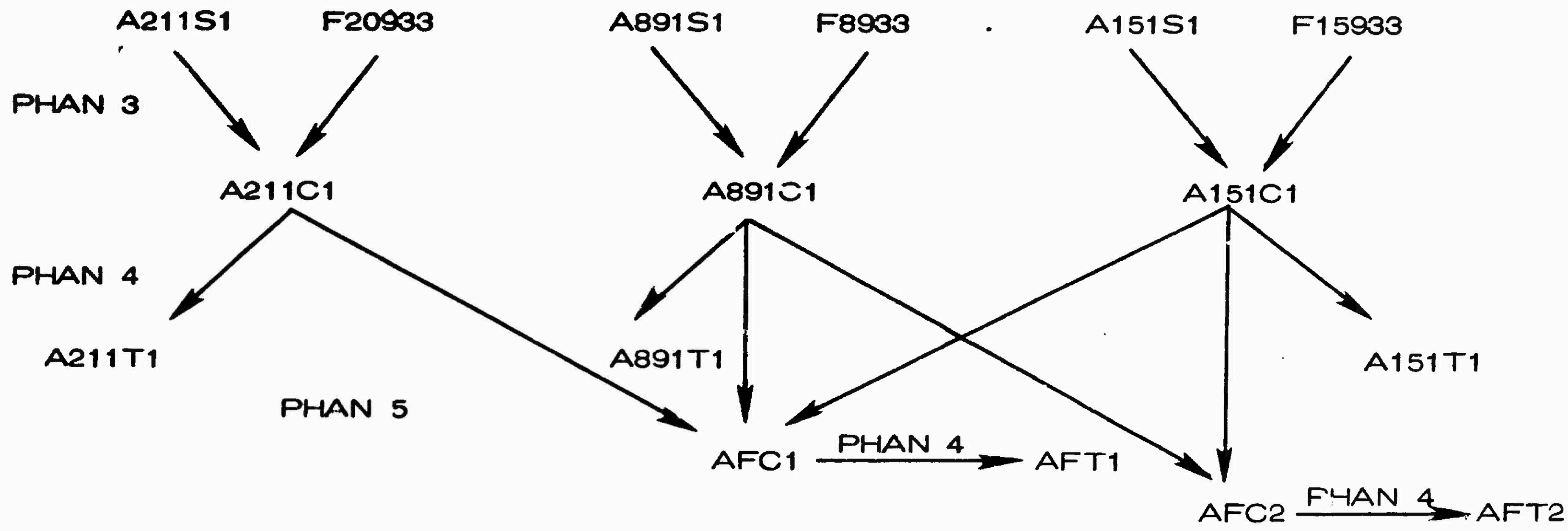

Figure A8. Computational Plan - Altitude

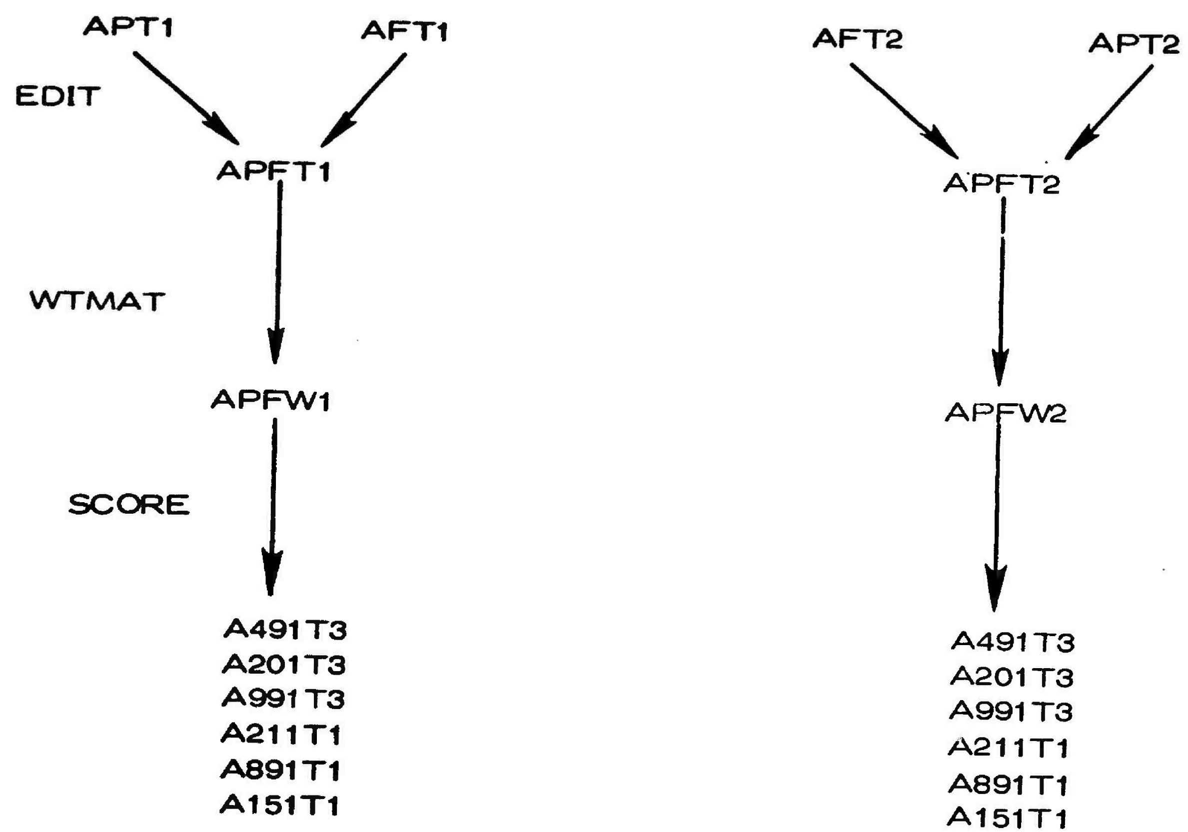

Figure A9. Computational Plan - Score Altitude

APPENDIX B

START/STOP INDICES

FOR

STRAIGHT AND LEVEL FLIGHT

FOR

SIX STUDENTS

Table B1

Straight/Level Flight - Altitude

Student 4935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	62	34.31	16.77	.46	4.23
124	187	48.41	19.69	- .40	4.16
244	262	4.47	10.45	.06	5.29
59	63	28.80	1.92	- 1.25	.50
93	111	44.05	11.75	- 2.22	9.58
119	140	66.73	7.64	- .10	4.52
148	169	41.36	19.71	- 2.33	5.43
169	175	25.00	4.43	2.00	1.67
227	239	9.85	37.54	6.17	16.63
277	296	- 85.75	15.02	1.74	8.92
314	332	-433.89	61.09	.94	25.51
476	495	-912.40	66.68	- 10.21	11.18
496	504	-948.00	26.96	8.25	10.83
554	565	29.17	10.09	1.09	5.38
598	608	97.45	47.70	12.40	8.80
644	655	127.83	55.19	- 15.55	9.08
693	704	285.33	16.42	5.09	10.39

Table B2

Straight/Level Flight - Airspeed

Student 4935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	62	.13	1.49	.01	.60
124	187	.71	2.03	.07	.61
244	262	2.56	1.73	.27	.75
59	63	1.32	.27	.00	.49
93	111	- 1.89	3.29	- .17	2.81
119	140	- 1.66	1.30	.14	1.15
148	169	2.67	1.57	.09	.79
169	175	1.46	.91	- .40	.31
227	239	5.58	1.56	- .05	1.16
277	296	.18	3.34	- .32	2.66
314	332	- 2.78	5.98	- .90	3.19
476	495	- 6.51	3.82	.79	3.06
496	504	2.80	3.45	.98	1.47
554	565	- 4.45	3.60	.65	1.12
598	608	1.47	4.80	- .54	4.13
644	655	5.50	1.86	.16	1.17
693	704	4.40	2.75	.22	1.83

Table B3

Straight/Level Flight - Heading

Student 4935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	62	2.44	3.27	.10	1.03
124	187	1.87	5.47	.00	1.45
224	262	- .30	4.25	.09	1.45
59	63	3.31	3.87	2.40	.37
93	111	3.57	11.51	.64	4.60
119	140	2.04	6.17	- .24	1.73
148	169	- .16	6.12	.35	1.50
169	175	4.70	3.09	- 1.32	.47
227	239	- 1.20	12.14	.17	9.82
277	296	-182.80	14.70	.64	4.80
314	332	-107.49	85.83	2.22	81.78
476	495	-181.11	12.75	2.81	5.81
496	504	16.98	12.30	4.27	.90
554	565	3.72	12.35	- 2.56	2.49
598	608	-180.20	5.06	- .83	3.08
644	655	6.79	8.83	- 2.23	.93
693	704	10.75	23.93	- 6.02	2.98

Table B4

Straight/Level Flight - Rate of Climb

Student 4935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	62	14.47	136.56	- 1.21	76.53
124	187	- 10.06	134.56	- 2.25	84.06
244	262	4.37	164.18	- 7.56	107.41
59	63	- 34.20	28.35	- 10.25	29.77
93	111	- 84.42	325.02	37.11	253.23
119	140	- 4.91	159.54	- .43	121.05
169	175	64.29	55.97	12.33	47.04
227	239	71.15	203.76	- 9.00	181.22
277	296	49.60	304.31	24.42	285.77
314	332	20.84	814.13	87.28	368.61
476	495	-319.25	356.55	- 23.63	265.76
496	504	227.00	351.27	- 17.50	316.13
554	565	41.92	170.25	- .36	105.45
598	608	409.45	301.33	11.10	295.70
644	655	-508.75	302.64	68.55	63.36
693	704	190.58	353.02	33.82	334.22

Table B5

Straight/Level Flight - Altitude

Student 20935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	9	-340.56	84.43	29.75	8.22
62	73	109.25	17.85	5.55	7.27
81	108	37.89	93.84	- 6.41	13.63
112	123	86.42	17.10	4.45	2.50
162	172	-719.95	52.85	16.60	3.63
177	195	-404.84	107.49	18.28	4.38
206	217	- 80.50	48.60	- 11.12	8.77
298	300	123.67	8.08	- 8.00	2.83
622	652	- 14.10	26.83	- 1.77	4.41
711	715	-572.20	32.15	- 20.50	2.65
741	745	-968.20	16.42	10.25	3.30
74	92	145.05	- 34.19	- 4.33	11.34
132	152	- 42.33	314.92	- 52.55	231.78
209	228	-138.50	50.74	- 8.11	9.14
327	334	- 27.38	20.67	- 8.00	5.20
281	301	97.19	34.15	2.90	8.32
446	465	-654.90	14.83	.68	5.99
474	481	-873.75	26.88	11.00	2.71
537	547	- 66.09	17.61	- 5.90	3.81
587	597	-102.36	19.27	5.00	4.69
625	636	9.50	7.78	- .82	4.17
646	664	- 55.16	4.22	.00	3.09

Table B6

Straight/Level Flight - Airspeed

Student 20935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	9	- .67	1.57	- .08	.1.18
62	73	- 31.05	4.70	.87	1.48
81	108	.54	7.50	.22	2.63
112	123	- 10.10	1.30	.38	149
162	172	3.55	.78	.00	.63
177	195	3.38	1.70	- .17	.61
206	217	3.70	1.88	.11	1.19
298	300	3.40	1.25	1.20	.85
622	652	- 10.70	5.55	- .32	1.24
711	715	4.92	.78	.45	.30
741	745	.96	.54	- .30	.35
74	92	- 10.14	10.17	1.67	2.51
132	152	.69	2.37	.39	1.68
209	228	.09	4.28	- .51	1.28
327	334	- 3.75	1.27	- .43	.83
281	301	3.23	2.48	- .06	1.03
446	465	- 2.22	3.87	.51	2.70
474	481	2.85	.95	.34	.32
537	547	- 1.31	2.82	- .78	.64
587	597	-174.01	4.63	- 1.55	3.70
625	636	- 8.55	2.90	.71	.45
646	664	- 19.33	2.60	- .33	1.31

Table B7

Straight/Level Flight - Heading

Student 20935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	9	44.90	17.25	- 6.04	2.04
62	73	-201.17	25.40	6.87	.78
81	108	-117.46	112.65	6.65	68.80
112	123	22.74	4.45	- 1.07	1.11
162	172	15.40	2.94	.70	1.20
177	195	2.65	4.12	- .37	1.36
206	217	- 18.98	9.55	- 2.39	1.46
298	300	25.94	6.31	- 6.31	.03
622	652	- 10.85	7.74	- .90	1.98
711	715	-572.20	32.15	- 20.50	2.65
741	745	24.73	5.45	3.41	1.28
74	92	-144.15	11.26	- .88	5.53
132	152	- .63	11.70	.83	3.18
209	228	- 15.39	14.54	1.38	3.75
327	334	- 8.35	7.89	- 2.90	1.54
281	301	- 63.00	150.08	11.93	80.51
446	465	- 17.38	5.13	.80	3.24
474	481	13.08	2.66	1.00	.37
537	547	- 11.16	4.36	- 1.42	.80
587	597	-174.01	4.63	- 1.55	3.70
625	636	- 8.19	2.50	- .41	1.34
646	664	- 7.20	10.45	1.06	2.06

Table B8

Straight/Level Flight - Rate of Climb

Student 20935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	9	917.11	302.32	- 87.38	153.24
62	73	181.25	223.91	- 7.73	157.78
81	108	-197.39	441.02	25.41	162.33
112	123	142.00	95.73	- 25.82	76.93
162	172	547.36	129.09	- 18.60	100.87
177	195	581.05	145.62	14.89	82.76
206	217	-313.58	315.32	- 19.73	247.23
298	300	-218.67	168.77	-163.50	102.53
622	652	- 50.65	140.24	5.13	100.70
711	715	-659.60	87.80	- 46.50	48.35
741	745	330.80	160.56	-111.00	108.93
74	92	-144.47	388.03	- 47.67	168.55
132	152	8.33	218.63	33.50	147.09
209	228	-251.00	299.12	29.32	221.41
327	334	-243.63	169.59	- 5.86	197.09
281	301	67.71	289.37	4.75	153.33
446	465	19.80	219.09	- 4.63	244.25
474	481	358.38	94.01	36.57	25.22
537	547	-202.91	142.51	28.00	149.22
587	597	186.91	133.59	9.30	155.20
625	636	- 20.17	137.65	- 33.91	90.48
648	664	- 4.47	102.60	8.06	106.99

Table B9

Straight/Level Flight - Altitude

Student 9935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	62	20.21	18.22	.44	6.44
62	124	39.75	17.78	.50	5.62
188	193	-1000.33	.82	.20	.84
254	272	64.95	64.65	- 5.17	16.12
324	342	- 7.32	22.22	2.17	6.08
250	363	6.46	50.71	- .59	12.11
389	395	- 992.14	4.57	1.50	2.88
512	530	113.79	39.00	7.00	5.49
9	14	20.33	2.16	.80	1.48
65	76	26.83	4.39	.73	2.76
113	124	43.67	16.65	2.18	7.45
196	207	- 859.83	72.79	20.45	4.82
293	299	-1001.71	1.72	- .83	.98
365	382	- 24.11	12.92	1.59	4.37
390	429	- 2.35	30.70	2.05	4.96
433	440	- 998.25	2.12	.43	1.51
520	559	152.38	44.87	2.15	8.83
644	664	101.05	44.32	4.85	6.11
774	778	- 566.40	17.71	- 11.25	.96
805	844	-1065.80	92.85	4.05	17.75

Table B10

Straight/Level Flight - Airspeed

Student 9935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	62	- .10	2.11	.00	.92
62	124	- .08	2.90	- .04	2.45
188	193	2.20	.49	.24	.54
254	272	5.24	7.26	.73	1.55
324	342	.32	3.70	- .13	2.67
250	363	.89	5.42	- .06	1.68
389	395	1.80	.49	.00	.54
512	530	- 5.27	2.73	.03	2.91
9	14	- .60	.00	.00	.00
65	76	.15	2.05	- .49	2.02
113	124	.50	4.15	- .50	2.34
196	207	- 4.35	2.35	- .65	.95
293	299	.69	.23	- .10	.24
365	382	- 4.83	1.33	.11	.49
390	429	- 5.58	2.78	- .20	.61
433	440	2.03	.31	- .09	.23
520	559	- 13.01	5.80	.43	1.04
644	664	- 13.46	2.23	.36	.98
744	778	- 6.48	.27	- .15	.30
805	844	- 10.67	6.57	- .54	1.42

Table B11

Straight/Level Flight - Heading

Student 9935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	62	3.10	7.80	.34	1.74
62	124	1.63	13.34	- .20	3.56
188	193	- 2.94	2.32	- 1.22	.25
254	272	1.22	14.02	- 2.23	1.88
324	342	-179.70	8.36	.76	3.60
250	363	- 99.28	122.22	- .02	47.22
389	395	- .08	.22	- .02	.22
512	530	-183.42	4.58	- .34	2.34
9	14	6.06	.75	.39	.22
65	76	- 1.37	6.73	- 1.91	2.59
113	124	16.67	4.92	- .61	3.85
196	207	- .98	4.45	1.08	.47
293	299	- 1.49	1.03	- .47	.09
365	382	- 10.99	3.70	- .64	1.16
390	429	- 9.53	7.37	- .22	2.30
433	440	- 3.04	1.70	- .71	.33
520	559	6.02	17.21	1.46	2.93
644	664	- .95	3.57	.47	1.50
774	778	-566.40	17.71	- 11.25	.96
805	844	-112.30	69.05	- 3.27	6.79

Table B12

Straight/Level Flight - Rate of Climb

Student 9935

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
1	62	15.61	207.72	3.05	108.05
62	124	23.22	187.21	- 5.29	180.90
188	193	7.00	19.80	8.40	16.09
254	272	-124.16	537.34	4.06	219.28
324	342	43.11	237.15	- 22.78	206.95
250	363	20.59	394.70	- 4.50	178.38
389	345	37.11	89.12	- 17.83	77.86
512	530	233.95	192.45	- 4.78	228.85
9	14	8.83	63.37	6.60	72.84
65	76	26.83	4.39	.73	2.76
113	124	68.33	230.05	19.91	177.95
196	207	644.58	150.85	2.00	121.67
293	299	- 26.86	32.15	- 12.00	13.46
365	382	53.83	135.96	- 5.94	61.29
390	429	58.40	165.69	3.51	88.66
433	440	12.25	39.75	- 1.57	48.61
520	559	76.03	288.96	- 18.72	87.03
644	664	147.29	193.76	1.75	81.49
744	778	-361.80	45.53	- 29.50	63.76
805	844	128.45	570.05	29.95	180.67

Table B13

Straight/Level Flight - Altitude

Student 20933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
13	30	166.39	29.22	4.94	8.47
34	56	149.00	21.84	- 2.50	4.09
64	82	118.16	18.03	- 1.00	5.39
153	172	-916.05	9.98	1.26	8.11
203	222	-448.50	14.98	.21	5.66
281	288	-997.00	1.93	.86	.69
332	365	-949.00	9.21	1.30	3.41
374	392	-857.26	37.71	5.50	7.29
441	459	- 17.58	19.68	1.28	7.07
544	562	80.42	7.58	- 1.06	2.67
632	651	-916.90	15.07	.84	7.78
678	696	-515.42	6.19	- .33	3.29

Table B14

Straight/Level Flight - Airspeed

Student 20933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
13	30	- 9.83	3.80	.28	3.15
34	56	- 2.11	1.95	.19	.65
64	82	- .28	2.09	.07	.77
153	172	- 3.36	2.03	.13	1.12
203	222	- 8.01	4.58	.47	.95
281	288	.30	.64	- .26	.32
332	365	- 15.42	2.47	.02	.63
374	392	- 3.76	1.96	.10	1.03
441	459	- 2.97	2.50	- .03	1.00
544	562	.51	.88	.07	.46
632	651	.87	5.10	.54	1.02
678	696	- 5.05	1.21	.20	.50

Table B15

Straight/Level Flight - Heading

Student 20933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
13	30	-172.65	5.78	.30	3.64
34	56	- 96.28	144.87	9.36	76.76
64	82	6.39	2.22	- .28	.80
153	172	5.04	3.32	.55	1.29
203	222	-156.05	11.44	- 1.17	2.25
281	288	.32	.45	.17	.15
332	365	1.59	5.67	.48	1.42
374	392	17.44	7.97	- 1.13	1.81
441	459	9.73	4.30	.23	2.03
544	562	3.16	3.28	- .38	.87
632	651	9.40	4.68	.17	1.73
678	696	-186.65	11.53	1.57	1.51

Table B16

Straight/Level Flight - Rate of Climb

Student 20933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
13	30	155.78	299.18	- 35.53	194.93
34	56	- 79.13	130.27	- 8.82	66.14
64	82	- 28.68	168.45	- 4.33	72.12
153	172	60.45	291.10	- 37.74	194.35
203	222	28.40	214.49	- 18.16	119.32
281	288	28.63	23.22	7.86	31.71
332	365	46.00	112.91	.94	47.57
374	392	173.47	254.72	32.78	181.51
441	459	28.84	238.32	10.83	145.83
544	562	- 34.58	85.17	.39	50.37
632	651	47.40	267.83	- 30.74	105.95
678	696	- 14.37	108.90	- 9.94	61.29

Table B17

Straight/Level Flight - Altitude

Student 8933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
30	37	- 442.00	31.85	13.00	.58
41	47	- 496.86	3.08	1.33	.82
77	84	- 863.62	40.17	- 16.29	1.70
96	102	- 989.71	16.94	6.50	5.47
104	137	- 997.12	20.00	.24	5.74
140	173	- 959.03	7.11	.03	2.97
284	302	41.84	15.64	1.67	6.45
330	348	47.21	23.15	- 3.72	5.90
381	399	58.58	6.04	.39	2.95
487	505	- 944.16	21.41	2.33	6.19
547	566	- 285.55	50.94	5.95	10.87
618	638	- 855.29	11.64	- .75	5.89
694	728	-1009.40	6.38	.41	2.95
823	842	- 10.80	13.67	1.16	5.53
878	896	- 22.47	20.88	- 2.11	8.59
928	946	- .84	7.12	.50	2.46
1013	1031	- 974.11	10.04	1.94	5.15
1073	1092	- 363.75	40.94	- 2.58	11.48

Table B18

Straight/Level Flight - Airspeed

Student 8933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
30	37	- 3.83	.31	.09	.41
41	47	.34	.59	- .30	.33
77	84	- 3.00	.32	- .09	.41
96	102	- 9.34	4.23	- 1.80	1.00
104	137	- 15.41	2.95	- .16	.95
140	173	- 17.72	1.93	.13	.58
284	302	- 3.25	4.21	.60	.80
330	348	- 1.29	4.68	.67	2.39
381	399	- 4.45	2.19	.33	.42
487	505	- 1.86	2.19	- .10	.99
547	566	- 2.64	7.10	1.20	.98
618	638	- 2.06	1.07	.12	.54
694	728	- 24.34	1.34	.00	.64
823	842	- 1.68	2.64	.19	.94
878	896	2.97	3.96	- .03	3.33
928	946	- .19	.80	.03	.44
1013	1031	- 1.17	1.50	- .30	.88
1073	1092	1.71	7.80	1.11	.73

Table B19

Straight/Level Flight - Heading

Student 8933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
30	37	-188.99	7.46	2.64	1.92
41	47	- 3.28	2.84	- 1.34	.69
77	84	-181.97	1.73	- .75	.73
96	102	- 4.62	1.61	- .79	.40
104	137	.06	6.31	.08	2.64
140	173	2.79	4.88	.06	1.47
284	302	- 1.84	3.64	.03	1.54
330	348	-183.24	4.08	.20	3.25
381	399	3.18	1.56	- .37	.46
487	505	- .97	2.75	- .00	1.04
547	566	-187.47	9.36	- 1.33	3.02
618	638	1.94	4.67	.21	1.68
694	728	.43	3.77	- .04	1.21
823	842	- 3.32	2.43	- .13	1.10
878	896	-179.92	3.69	.42	3.97
928	946	6.84	1.49	- .21	.36
1013	1031	.57	1.08	.24	.73
1073	1092	-174.33	7.16	- 1.08	.82

Table B20

Straight/Level Flight - Rate of Climb

Student 8933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
30	37	414.38	16.73	5.43	19.74
41	47	37.86	24.91	7.50	24.21
77	84	-517.75	58.26	23.14	58.59
96	102	171.57	193.68	22.83	204.61
104	137	8.18	184.28	1.88	102.02
140	173	.65	94.11	- 5.94	57.13
284	302	61.05	214.97	- 27.28	128.37
330	348	-106.32	205.51	- 17.39	203.14
381	399	13.95	95.26	- 13.33	63.40
487	505	56.84	213.94	9.00	141.63
547	566	188.15	357.45	- 44.32	154.70
618	638	- 29.71	193.25	- 19.20	119.34
694	728	16.29	100.43	- 8.15	78.49
823	842	43.30	176.93	2.89	101.71
879	896	- 72.53	287.34	.50	246.48
928	946	16.63	78.14	- 8.89	49.62
1013	1031	60.63	165.75	- .94	118.95
1073	1092	- 66.05	380.71	- 43.16	143.83

Table B21

Straight/Level Flight - Altitude

Student 15933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
6	10	- 950.60	16.94	10.50	.1:29
45	52	- 446.75	13.68	6.43	6.45
56	62	- 502.14	4.53	- 2.00	3.63
90	97	- 970.63	16.03	1.71	13.60
102	109	- 994.00	7.84	3.00	2.83
117	149	- 908.58	20.20	1.84	5.46
197	215	- 745.79	35.76	- 4.11	9.38
262	281	122.75	39.17	6.06	4.74
286	315	187.27	46.05	- 3.93	5.14
349	368	- 5.70	16.12	2.06	6.11
376	394	80.68	21.86	- 2.67	4.85
466	485	- 928.40	67.99	- 4.16	18.01
522	541	- 428.60	39.29	- 6.47	5.22
571	591	- 923.76	37.99	2.30	10.83
672	674	-1299.00	12.00	12.00	.00
696	700	-1107.00	10.32	- 6.25	1.71
768	777	7.00	3.65	- 1.00	1.87
785	804	25.15	21.77	3.26	4.17
861	879	12.89	5.76	- .5[illegible]	3.28
971	975	- 916.40	27.37	17.00	1.83

Table B22

Straight/Level Flight - Airspeed

Student 15933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
6	10	- 2.88	.27	- .15	.30
95	52	- 8.85	1.19	.26	.76
56	62	.77	.29	.00	.38
90	97	- 8.10	2.05	- .86	.68
102	109	- .52	1.41	- .60	.35
117	149	- 15.91	2.22	- .19	1.02
197	215	.03	5.61	.77	1.09
262	281	- 15.57	3.07	.41	.94
236	315	- 3.40	5.72	.54	.84
349	368	- 1.56	2.98	- .54	.75
376	394	- 3.95	4.18	.60	.62
466	485	- 1.50	7.64	.41	2.06
522	541	- 3.54	6.14	1.04	.89
571	591	- 2.17	4.83	.15	1.57
672	674	- 4.20	.00	.00	.00
696	700	- 7.44	2.87	1.80	.49
768	777	- 2.52	.47	- .07	.36
785	804	- 3.54	1.94	- .25	.67
861	879	- 1.67	1.19	.23	.59
971	975	2.52	.78	- .45	.30

Table B23

Straight/Level Flight - Heading

Student 15933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
6	10	7.39	7.35	4.51	1.88
45	52	-179.33	3.89	- 1.60	.49
56	62	- 4.20	4.76	- 2.20	1.94
90	97	-198.38	8.89	1.73	6.31
102	109	- .57	.36	- .10	.17
117	149	- 23.96	51.06	3.57	6.57
197	215	4.77	28.20	4.64	2.77
262	281	- 80.87	32.14	5.51	.80
286	315	- 78.40	138.29	- 6.23	66.83
349	368	- 38.86	144.60	13.35	82.72
376	394	2.50	4.57	- .92	.79
466	485	17.40	12.89	- .70	3.84
522	541	-184.47	4.57	- .25	2.10
571	59[illegible]	- .54	5.56	1.13	3.09
672	674	7.55	8.16	8.15	1.20
696	700	-188.18	16.95	10.77	.88
768	777	- .50	1.27	- .05	.92
785	804	-112.81	149.45	- 12.58	82.42
861	879	.51	3.41	.38	1.09
971	975	- 16.87	6.86	- 4.26	1.36

Table B24

Straight/Level Flight - Rate of Climb

Student 15933

Start	Stop	$\bar{y}$ of Error	$\hat{s}$ of Error	$\bar{y}$ Error Rate	$\hat{s}$ Error Rate
6	10	325.80	53.99	14.75	81.92
45	52	235.13	216.54	- 35.14	210.48
56	62	- 81.86	147.60	- 65.83	106.50
90	97	65.38	440.30	136.29	170.61
102	109	97.50	99.53	37.57	29.30
117	149	59.91	181.03	4.44	157.82
197	215	-123.95	300.51	6.39	184.64
262	281	192.95	151.42	- 6.00	86.10
286	315	-122.50	177.88	- 19.48	130.02
349	368	67.25	195.57	17.53	91.84
376	394	- 77.47	156.07	- 1.44	100.26
466	485	- 86.70	598.71	- 3.63	245.16
522	541	-192.75	184.30	- 5.26	192.29
571	591	72.86	340.02	- 6.30	168.97
672	674	344.00	75.11	29.00	169.71
696	700	-158.20	118.92	43.25	160.79
768	777	- 26.20	69.17	22.44	39.74
785	804	93.65	139.39	5.89	88.49
861	879	- 14.05	112.17	9.39	101.59
971	975	499.40	110.64	19.50	146.98

APPENDIX C

TABLES OF PROBABILITIES OF CELL USAGE

Table C1

Probability of Cell Usage - Altitude

Students 20935, 9935, 4935

Student 20935			Student 9935			Student 4935		
Cells		Probability of Usage	Cells		Probability of Usage	Cells		Probability of Usage
13	13	0.0700	5	5	0.0819	13	13	0.0859
1	1	0.0687	12	12	0.0688	12	12	0.0661
2	2	0.0487	8	8	0.0677	16	16	0.0542
5	5	0.0479	11	11	0.0655	8	8	0.0399
25	25	0.0448	13	13	0.0528	5	5	0.0391
24	24	0.0336	15	15	0.0521	25	25	0.0385
12	12	0.0330	18	18	0.0472	11	6	0.0324
11	11	0.0324	6	6	0.0457	7	7	0.0299
6	6	0.0307	7	7	0.0323	6	1	0.0283
21	21	0.0306	25	25	0.0316	19	19	0.0276
7	7	0.0298	12	7	0.0256	9	9	0.0271
10	10	0.0293	21	21	0.0192	1	1	0.0267
18	18	0.0285	20	20	0.0190	10	10	0.0227
8	8	0.0280	8	13	0.0155	8	13	0.0209
19	19	0.0261	7	12	0.0148	14	19	0.0190
23	23	0.0251	7	8	0.0148	19	14	0.0181
14	19	0.0214	17	12	0.0137	9	14	0.0163
16	11	0.0207	18	17	0.0131	4	9	0.0158
21	16	0.0204	18	13	0.0131	20	25	0.0148
19	14	0.0196	16	11	0.0121	2	7	0.0143
24	23	0.0165	10	5	0.0118	1	6	0.0133
12	7	0.0163	19	19	0.0118	1	2	0.0133
11	6	0.0162	19	18	0.0118	25	20	0.0126
6	1	0.0139	11	6	0.0116	15	15	0.0120
19	24	0.0131	1	1	0.0116	15	5	0.0120

Table C2

Probability of Cell Usage - Airspeed

Students 20935, 9935, 4935

Student 20935			Student 9935			Student 4935		
Cells		Probability of Usage	Cells		Probability of Usage	Cells		Probability of Usage
12	12	0.1606	13	13	0.1072	13	13	0.1800
15	15	0.0711	15	15	0.0883	12	12	0.0913
13	13	0.0607	12	12	0.0689	14	14	0.0837
6	6	0.0427	10	10	0.0452	11	11	0.0453
21	21	0.0398	14	14	0.0411	20	20	0.0237
11	11	0.0341	25	25	0.0379	7	12	0.0155
10	10	0.0316	16	16	0.0360	1	7	0.0144
20	20	0.0297	11	11	0.0333	18	17	0.0140
12	7	0.0294	10	15	0.0258	16	11	0.0139
7	12	0.0288	21	21	0.0241	11	6	0.0139
11	6	0.0218	20	20	0.0210	15	25	0.0134
6	11	0.0214	6	6	0.0186	15	15	0.0134
10	15	0.0207	21	16	0.0182	13	8	0.0130
15	20	0.0203	15	20	0.0172	19	14	0.0129
11	12	0.0171	11	6	0.0166	8	8	0.0116
17	17	0.0157	1	1	0.0136	7	8	0.0115
17	16	0.0157	15	10	0.0135	7	7	0.0115
17	12	0.0157	19	18	0.0131	12	17	0.0109
16	16	0.0153	2	4	0.0115	12	13	0.0109
16	11	0.0153	6	11	0.0113	12	7	0.0109
16	6	0.0153	6	1	0.0113	13	12	0.0108
1	6	0.0135	20	15	0.0111	25	13	0.0106
13	18	0.0132	14	19	0.0109	17	7	0.0106
6	1	0.0125	12	13	0.0105	18	13	0.0105
8	13	0.0124	12	7	0.0105	22	1	0.0097

Table C3

Probability of Cell Usage - Heading

Students 20935, 9935, 4935

Student 20935			Student 9935			Student 4935		
Cells		Probability of Usage	Cells		Probability of Usage	Cells		Probability of Usage
8	8	0.1263	13	13	0.1091	13	13	0.1100
5	5	0.1060	15	15	0.1072	12	12	0.0570
21	21	0.0806	12	12	0.0502	21	21	0.0552
12	12	0.0562	1	1	0.0391	14	14	0.0528
11	11	0.0510	11	11	0.0369	25	25	0.0520
13	13	0.0488	14	14	0.0359	16	16	0.0449
20	20	0.0398	5	5	0.0354	20	20	0.0333
15	15	0.0378	16	16	0.0350	15	15	0.0266
25	25	0.0348	6	6	0.0301	6	6	0.0261
16	16	0.0333	25	25	0.0255	18	18	0.0246
10	10	0.0283	10	15	0.0255	5	5	0.0230
14	14	0.0280	15	20	0.0246	18	17	0.0207
6	6	0.0216	20	20	0.0225	7	8	0.0197
10	15	0.0194	17	17	0.0210	16	11	0.0181
15	10	0.0131	10	10	0.0178	17	12	0.0180
21	16	0.0119	7	7	0.0131	8	13	0.0167
5	10	0.0112	17	16	0.0126	7	7	0.0161
10	5	0.0112	8	8	0.0122	25	20	0.0152
15	20	0.0110	11	6	0.0121	10	10	0.0145
25	20	0.0102	6	1	0.0119	11	21	0.0140
16	21	0.0093	16	11	0.0115	21	1	0.0136
16	11	0.0093	18	18	0.0105	8	8	0.0123
7	8	0.0089	18	17	0.0105	15	20	0.0120
11	6	0.0082	9	10	0.0104	14	19	0.0109
12	13	0.0079	20	25	0.0100	1	25	0.0107

Table C4

Probability of Cell Usage - Altitude

Students 15933, 20933, 8933

Student 15933			Student 20933			Student 8933		
Cells		Probability of Usage	Cells		Probability of Usage	Cells		Probability of Usage
13	13	0.0799	15	15	0.1085	13	13	0.1578
16	16	0.0737	11	11	0.0931	12	12	0.1498
15	15	0.0649	12	12	0.0779	15	15	0.1303
8	8	0.0612	13	13	0.0643	17	17	0.0713
11	11	0.0595	18	18	0.0522	18	18	0.0428
12	12	0.0540	10	10	0.0435	20	20	0.0369
7	7	0.0490	14	14	0.0378	8	8	0.0346
17	17	0.0430	3	3	0.0378	17	12	0.0291
5	5	0.0362	6	6	0.0300	7	7	0.0245
25	25	0.0357	16	16	0.0277	25	25	0.0231
20	20	0.0286	16	11	0.0277	13	18	0.0220
10	10	0.0254	18	13	0.0257	13	8	0.0220
18	18	0.0235	13	8	0.0214	8	13	0.0198
6	6	0.0218	7	7	0.0199	10	10	0.0197
16	11	0.0218	1	1	0.0199	12	7	0.0196
10	15	0.0207	19	18	0.0189	10	15	0.0184
7	12	0.0193	17	17	0.0189	5	5	0.0181
11	16	0.0177	14	19	0.0186	15	10	0.0175
15	20	0.0174	3	8	0.0186	18	17	0.0171
20	15	0.0170	8	14	0.0186	18	13	0.0171
5	10	0.0170	8	8	0.0186	20	15	0.0138
8	13	0.0163	8	3	0.0186	7	12	0.0122
12	17	0.0152	20	20	0.0169	15	20	0.0111
12	7	0.0152	10	15	0.0161	23	18	0.0100
17	12	0.0143	5	5	0.0142	8	3	0.0096

Table C5

Probability of Cell Usage - Airspeed

Students 15933, 20933, 8933

Student 15933			Student 20933			Student 8933		
Cells		Probability of Usage	Cells		Probability of Usage	Cells		Probability of Usage
15	15	0.1710	15	15	0.2250	15	15	0.2341
13	13	0.1709	14	14	0.1667	13	13	0.2014
10	10	0.0516	13	13	0.1305	14	14	0.1002
12	12	0.0511	10	10	0.0269	10	15	0.0448
14	14	0.0473	8	14	0.0269	15	10	0.0322
10	15	0.0389	8	8	0.0269	20	20	0.0295
15	10	0.0238	15	20	0.0219	10	10	0.0261
11	6	0.0238	13	8	0.0186	15	20	0.0234
15	20	0.0195	9	15	0.0183	12	12	0.0228
20	20	0.0194	14	19	0.0160	20	15	0.0212
6	6	0.0188	14	15	0.0160	9	9	0.0198
7	13	0.0162	14	13	0.0160	8	9	0.0175
7	8	0.0162	14	9	0.0160	9	10	0.0148
7	7	0.0162	10	15	0.0159	13	14	0.0141
9	10	0.0159	7	8	0.0156	8	8	0.0131
16	11	0.0159	20	15	0.0146	13	8	0.0117
8	9	0.0152	15	10	0.0137	7	7	0.0096
6	7	0.0141	19	19	0.0121	12	13	0.0090
11	11	0.0141	19	13	0.0121	19	18	0.0081
18	18	0.0131	8	13	0.0106	7	12	0.0071
14	19	0.0127	13	14	0.0102	7	8	0.0071
9	14	0.0119	12	12	0.0101	14	19	0.0058
20	15	0.0112	5	20	0.0099	20	24	0.0053
8	14	0.0102	5	5	0.0099	24	17	0.0052
12	16	0.0094	20	10	0.0098	9	20	0.0049

Table C6

Probability of Cell Usage - Heading

Students 15933, 20933, 8933

Student 15933			Student 20933			Student 8933		
Cells		Probability of Usage	Cells		Probability of Usage	Cells		Probability of Usage
5	5	0.1987	25	25	0.1468	13	13	0.1743
13	13	0.1042	12	12	0.1266	12	12	0.0409
1	1	0.0643	13	13	0.1013	14	14	0.1348
21	21	0.0465	11	11	0.0896	15	15	0.1191
12	12	0.0447	14	14	0.0658	8	8	0.0271
25	25	0.0434	21	21	0.0543	14	19	0.0228
14	14	0.0339	15	15	0.0518	9	14	0.0200
6	6	0.0292	20	20	0.0368	18	13	0.0177
11	11	0.0206	10	10	0.0324	19	19	0.0177
11	6	0.0206	15	10	0.0218	13	12	0.0177
16	11	0.0182	16	11	0.0205	20	20	0.0166
15	15	0.0181	11	7	0.0160	20	15	0.0166
4	5	0.0149	10	15	0.0159	8	9	0.0161
15	20	0.0145	6	6	0.0145	18	18	0.0142
20	20	0.0138	7	12	0.0115	13	18	0.0132
10	5	0.01[illegible]	7	7	0.0115	8	14	0.0110
1	2	0.0114	14	13	0.0107	8	13	0.0110
2	3	0.0109	11	16	0.0086	25	20	0.0108
20	15	0.0108	11	6	0.0086	19	13	0.0106
5	10	0.0108	13	18	0.0082	14	13	0.0105
19	19	0.0106	13	12	0.0082	12	7	0.0095
3	4	0.0105	20	15	0.0081	2	8	0.0094
11	16	0.0103	1	25	0.0077	10	10	0.0082
8	13	0.0100	7	13	0.0077	7	8	0.0072
8	8	0.0100	7	8	0.0077	15	25	0.0072

APPENDIX D

SIMULATION OF THE EFFECT OF OPERATOR PERFORMANCE

ON

A NEAR TERM SCOUT MISSION

```
FORTRAN IV      V01A-1    THU 14-MAY-81 03:34:00              PAGE 001

      C PROGRAM 'NTSMIS.FOR'
      C DATE: 4-APRIL-81
      C
      C PURPOSE: COMPUTE THE PROBABILITY OF TARGET KILL
      C FOR THE NEAR TERM SCOUT MISSION.
      C
0001        DIMENSION ITITLE(64,25),KURR1(64),KURR2(64),IDOC(40),IMID(20)
0002        DATA ITITLE/1600*'  '/,KURR1/64*0.0/,KURR2/64*0.0/,
           1     IDOC/40*'  '/,IMID/20*0/,IRUNS/0/
      C
      C READ THE PROBLEM INPUT PARAMETERS
      C
0003        WRITE(7,7100)
0004        READ(5,5100) IDUM
0005        WRITE(7,7110)
0006        CALL ASSIGN(2,'  ',-1,'RDO','NC',1)
0007        WRITE(7,7120)
0008        READ(5,5110) ISEED1,ISEED2
0009        WRITE(7,7130)
0010        READ(5,5100) NSIM
0011        WRITE(7,7140)
0012        READ(5,5100) IDEBUG
0013        WRITE(7,7150)
0014        READ(5,5100) IUNIT
0015        WRITE(7,7160)
0016        READ(5,5120) (IDOC(I),I=1,40)
0017        IF((IUNIT.EQ.6).OR.(IUNIT.EQ.7)) GO TO 10
0019        IUNIT=7
0020     10 CONTINUE
0021        CALL INPUT(ITITLE,KURR1,NUMURR)
0022        CALL CLOSE(2)
0023        GO TO 200
      C
      C CHECK IF ANOTHER SIMULATION DESIRED
      C
0024    100 CONTINUE
0025        WRITE(7,7170)
0026        READ(5,5100) IDUM
0027        IF(IDUM.NE.0) GO TO 300
      C
      C SET SEEDS AND MODIFY INPUT PARAMETERS AS DESIRED
      C
0029    200 CONTINUE
0030        IRUNS=IRUNS+1
0031        IS1=ISEED1
0032        IS2=ISEED2
0033        CALL REVIEW(ITITLE,KURR1,KURR2,NUMURR)
      C
      C PERFORM SIMULATED MISSIONS
      C
0034        CALL NTSMIS(KURR2,IS1,IS2,LAST1,LAST2,NSIM,IDEBUG,
           1            AKILL,SOP,IMID)
      C
      C PRINT THE RESULTS
```

```
C
        CALL PRINT(ITITLE,KVAR2,IS1,IS2,LAST1,LAST2,NSIM,
     1            APKILL,SDKP,IMOD,IDOC,IRUNS,IUNIT,NUMVAR)
        ISEED1=LAST1
        ISEED2=LAST2
        GO TO 100
  300   CONTINUE
        STOP 'END OF PROGRAM - NEAR TERM SCOUT MISSION - (NTSMIS)'
 5100   FORMAT(I7)
 5110   FORMAT(2I7)
 5120   FORMAT(40A2)
 7100   FORMAT(' ','PROGRAM NTSMIS - NEAR TERM SCOUT MISSION'/
     1 ' '//' ','INSERT THE DATA DISC IN UNIT DK: AND HIT RETURN')
 7110   FORMAT(' ','NAME THE INPUT DATA FILE (ASSIGN)'/)
 7120   FORMAT(' ','ENTER THE TWO RANDOM INTEGER SEEDS')
 7130   FORMAT(' ','ENTER THE NUMBER OF SIMULATIONS TO PERFORM')
 7140   FORMAT(' ','ENTER THE DEBUG SWITCH (IF NOT ZERO OPTION TRUE)')
 7150   FORMAT(' ','ENTER THE OUTPUT UNIT NUMBER (6=LP:,7=TT:)')
 7160   FORMAT(' ','ENTER THE TITLE OF THIS RUN (80 CHARACTERS)')
 7170   FORMAT(' ','HIT RETURN TO PERFORM ANOTHER SIMULATION, ',
     1            'ELSE ENTER VALUE NOT EQUAL TO ZERO (1)')
        END
```

```
      SUBROUTINE INPUT(ITITLE,RVAR1,NUMVAR)
      DIMENSION ITITLE(64,25),RVAR1(64)
      NUMVAR=0
  100 CONTINUE
      NUMVAR=NUMVAR+1
      READ(2,2000,END=200) (ITITLE(NUMVAR,J),J=1,25),RVAR1(NUMVAR)
      GO TO 100
  200 CONTINUE
      NUMVAR=NUMVAR-1
      RETURN
 2000 FORMAT(25A2/F13.7)
      END
```

```
0001          SUBROUTINE REVIEW(ITITLE,RVAR1,RVAR2,NUMVAR)
0002          DIMENSION ITITLE(64,25),RVAR1(64),RVAR2(64)
0003          WRITE(7,7100)
0004          DO 100 I=1,NUMVAR
0005          WRITE(7,7110) (ITITLE(I,J),J=1,25),RVAR1(I)
0006          READ(5,5100) DUMMY
0007          IF(DUMMY.EQ.0.0) RVAR2(I)=RVAR1(I)
0009          IF(DUMMY.NE.0.0) RVAR2(I)=DUMMY
0011     100  CONTINUE
0012          RETURN
0013    5100  FORMAT(F13.7)
0014    7100  FORMAT(' ',/,' HIT RETURN TO ACCEPT VALUE,',
             1           ' ELSE ENTER NEW VALUE',/,' ')
0015    7110  FORMAT(' ',25A2,1X,F13.7,$)
0016          END
```

```
0001        SUBROUTINE MTSMIS(RVAR2,IS1,IS2,LAST1,LAST2,NSIM,IDEBUG,
          1                     APKILL,SDKP,IPKD)
0002        DIMENSION RVAR2(64),IPKD(20)
      C
      C INTILIZE COUNTS
      C
0003        I1=IS1
0004        I2=IS2
0005        SUMP=0.0
0006        SUMP2=0.0
0007        DO 100 I=1,20
0008        IPKD(I)=0
0009    100 CONTINUE
      C
      C SET VARIABLES
      C
0010        RANGE=RVAR2(1)
0011        HEIGHT=RVAR2(2)
0012        XERR=RVAR2(3)
0013        YERR=RVAR2(4)
0014        TSINCE=RVAR2(5)
0015        SDAME=RVAR2(6)
0016        SDVME=RVAR2(7)
0017        PDEERR=RVAR2(8)
0018        XDEMAX=RVAR2(9)
0019        YDEMAX=RVAR2(10)
0020        PTOFE=RVAR2(11)
0021        TOFMAX=RVAR2(12)
0022        PIDHIT=RVAR2(13)
0023        DMKILL=RVAR2(14)
      C
      C COMPUTE RANGE OF DATA ENTRY ERRORS
      C
0024        XERRN=XDEMAX*2.0
0025        YERRN=YDEMAX*2.0
      C
      C TIME OF FLIGHT ERROR RANGE
      C
0026        TOFERN=TOFMAX*2.0
      C
      C COMPUTE NAVIGATION ERROR
      C
0027        XE1=XERRN*TSINCE
0028        YE1=YERRN*TSINCE
      C
      C PERFORM THE SIMULATED MISSIONS
      C
0029        DO 600 IM=1,NSIM
      C
      C COMPUTE THE MEASUREMENT ERROR
      C
0030        CALL RNORML(I1,I2,0.0,SDAME,VAL1)
0031        XE2=RANGE*COS(VAL1)-RANGE
0032        IF(VAL1.GT.0.0) XE2=-XE2
```

```
0034        YE2=RANGE*SIN(VAL1)
0035        CALL RNORML(I1,I2,0.0,SDVNE,VAL2)
0036        XE4=RANGE*(1.0-(1.0/COS(VAL2)))
0037        IF(VAL2.GT.0.0) XE4=-XE4
      C
      C COMPUTE DATA ENTRY ERRORS
      C
0039        RUD=RAN(I1,I2)
0040        XE3=0.0
0041        IF(RUD.GT.PDEERR) GO TO 200
0043        RUD=RAN(I1,I2)
0044        XE3=-XDEMAX+RUD*XERAN
0045    200 CONTINUE
0046        RUD=RAN(I1,I2)
0047        YE3=0.0
0048        IF(RUD.GT.PDEERR) GO TO 300
0050        RUD=RAN(I1,I2)
0051        YE3=-YDEMAX+RUD*YERAN
0052    300 CONTINUE
      C
      C COMPUTE THE MISS DISTANCE
      C
0053        XLOC=XE1+XE2+XE3+XE4
0054        YLOC=YE1+YE2+YE3
0055        DIST=SQRT(XLOC**2+YLOC**2)
0056        AJDIST=DIST
0057        IF(DIST.GT.DMFILL) AJDIST=DMFILL
      C
      C PKILL PROBABILITY BASED ON LOCATION ERROR OF TARGET
      C
0059        PKILL1=(1.0-(AJDIST/DMFILL))*PKDHIT
      C
      C TIME OF FLIGHT ERROR
      C
0060        RUD=RAN(I1,I2)
0061        TOFERR=0.0
0062        IF(RUD.GT.PTOFE) GO TO 500
0064        RUD=RAN(I1,I2)
0065        TOFERR=-TOFMAX+RUD*TOFRAN
0066    500 CONTINUE
0067        PKILL2=(1.0-ABS(TOFERR/TOFMAX))*PKIHIT
      C
      C COLLECT THE STATISTICS OF THIS RUN
      C
0069        PKILL=PKILL1*PKILL2
0070        ISUB=IFIX(PKILL/0.05+0.5)
0071        IF(ISUB.LT.1) ISUB=1
0072        IF(ISUB.GT.20) ISUB=20
0074        IHIT(ISUB)=IHIT(ISUB)+1
0075        SUMP=SUMP+PKILL
0076        SUMP2=SUMP2+PKILL**2
      C
      C [illegible]
      C
```

```
0077          IF(IDEBUG.EQ.0) GO TO 600
0079          WRITE(7,7000) INT,PKILL,PKILL1,PKILL2,VAL1,VAL2,
            1               XE1,XE2,XE3,XE4,YE1,YE2,YE3,
            2               XLOC,YLOC,DIST,AJDIST,TOFERR
0080     600 CONTINUE
0081          APKILL=SUMP/FLOAT(NSIM)
0082          SDKP=SQRT(ABS((SUMP2-(SUMP**2/FLOAT(NSIM-1)))/FLOAT(NSIM-1)))
0083          LAST1=11
0084          LAST2=12
0085          RETURN
0086    7000 FORMAT(' ',I6,1X,3F8.2,2F10.5/' ',7F10.3/' ',5F10.3)
0087          END
```

```
      SUBROUTINE RNORML(IR1,IR2,XMEAN,XSDEV,VALUE)
      XSUM=0.0
      DO 100 I=1,12
      XSUM=XSUM+RAN(IR1,IR2)
  100 CONTINUE
      ZSCORE=((XSUM/12.0)-0.5)/0.08333
      VALUE=XMEAN+XSDEV*ZSCORE
      RETURN
      END
```

```
0001        SUBROUTINE PRINT(ITITLE,RVAR2,IS1,IS2,LAST1,LAST2,NSIM,
           1                 AAKILL,SDKP,IPKD,IDOC,IRUNS,IUNIT,NUMVAR)
0002        DIMENSION ITITLE(64,25),RVAR2(64),IPKD(20),IDOC(40)
0003        WRITE(IUNIT,7610) IRUNS,(IDOC(I),I=1,40)
0004        DO 100 I=1,NUMVAR
0005        WRITE(IUNIT,7620) (ITITLE(I,J),J=1,25),RVAR2(I)
0006    100 CONTINUE
0007        WRITE(IUNIT,7630) IS1,IS2,LAST1,LAST2,NSIM
0008        WRITE(IUNIT,7640) AAKILL,SDKP
0009        WRITE(IUNIT,7650) (IPKD(I),I=1,20)
0010        RETURN
0011   7610 FORMAT( 1   NEAR TERM SCOUT MISSION SIMULATION - RUN NUMBER: ',I4/
           1 ' ',40A2' '/
           2 ' ','VARIABLE DESCRIPTION',42X,'VALUE'/
           3 ' ',-------------------',42X,'-----'//' ')
0012   7620 FORMAT( ' ',25A2,4X,F13.5)
0013   7630 FORMAT( /       ,'BEGINNING SEEDS: ',2I8/
           1 ' ','ENDING SEEDS: ',2I8/
           2 ' ','NUMBER OF MISSIONS SIMULATED: ',I6//' ')
0014   7640 FORMAT(' ','AVERAGE KILL PROBABILITY: ',F8.5/
           1 ' ','STANDARD DEVIATION OF KILL PROBABILITY: ',F13.7)
0015   7650 FORMAT(      ,'KILL DISTRIBUTION FOLLOWS:'/
           1 ' ',10I7,' ',10I7)
0016        END
```